ECOLOGY OF CHITAL (*Axis axis*) IN GIR

THESIS SUBMITTED TO THE
SAURASHTRA UNIVERSITY
RAJKOT (GUJARAT)

FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY
In
WILDLIFE SCIENCE

By
Chittaranjan Dave

Under guidance of
Dr. Y. V. Jhala

भारतीय वन्यजीव संस्थान
Wildlife Institute of India

May 2008

Certificate

Date:

This is to certify that the thesis titled **"Ecology of Chital (*Axis axis*) in Gir"** submitted for the award of degree of **Doctor of Philosophy** in **Wildlife Science** to the Saurashtra University, Rajkot is a record of original and independent work carried out by **Mr. Chittaranjan Dave** under my guidance. No part of this thesis has been submitted in part or full to any other University/Institution for the award of any other degree and it fulfils all the requirements laid down by Saurashtra University.

Yadvendradev Jhala (Ph. D.)
Professor
Animal Ecology &
Conservation Biology
Department

Forwarded by

Dr. V. B. Mathur
Dean,
Faculty of Wildlife Science
Wildlife Institute of India

To be an ecologist is to live

"alone in a world of wounds."

- Aldo Leopold (1953)

Leopold, A. (1953) Round River: from the journals of Aldo Leopold. L. B. Leopold, editor. Oxford University Press, New York, New York.

CONTENTS

ACKNOWLEDGEMENT

This is a response of my soul to all those without whom I would have never seen this pleasant moment. My first obligation irredeemable by verbal expression is to that loving, homely and generous institution – Wildlife Institute of India, the only abode of wildlife researchers in Southeast Asia.

I feel short of words to acknowledge my supervisor, Dr. Y. V. Jhala; his constant inspiration, moral support, valuable advice and tough training helped shaping up this thesis. May be, for rest of the world he is an eminent wildlife scientist but for me he is my ideal, my guru and my guardian. I will be always indebted to him for upbringing me in the field of wildlife science.

I extend my sincere thanks to Mr. P. R. Sinha, Director, WII and former directors for providing me all facilities and supports. I am really grateful to Dr. V. B. Mathur, Dean, WII for his constant support and facilitation. I thank former dean Dr. A. J. T. Johnsingh for his critics, comments and suggestions during the proposal development stage of this study.

At this moment, I feel pleasure to acknowledge all respected faculties at WII for moral encouragement. Mr. Qamar Qureshi, one of the investigators of the project, has taught me many theoretical and statistical concepts. I thank him for always being available to feed into new ideas every time. I thank Dr. K. Sankar, Research Coordinator for facilitating my research work. I am also thankful to Dr. Hussain, hostel warden for providing hostel facilities. I am grateful to library, laboratory, herbarium, computer and GIS cell for the timely assistance. My heartiest thank to Dr. G .S. Rawat for his valuable comments and suggestion. I am indebted to him for reviewing one full chapter at short notice. I would also like to thank Dr. P.K. Mathur for sparing his valuable time and discussing various issues of this thesis from time to time. I am also thankful to Dr. S. P. Goyal and Dr. K. Vasudevan for many informative as well as interesting discussions. My special thanks to Dr. Asha Rajvanshi for providing me several opportunities to gain experience on impact analysis studies of various developmental activities. I am grateful to Ct. Dr. Parag Nigam as I have learnt a lot about wildlife health and diseases during several cheerful informal interactions. I thank Mrs. Bitapi Sinha, nodal officer, Audio-Visual Unit, for facilitating the printing of colour plates.

I sincerely acknowledge and thank Gujarat Forest Department, especially the management staff of Gir for providing me logistic help and support during field work. Mr. Bharat Pathak, IFS, CF Junagadh was immensely supportive throughout the study, I thank him for his valuable suggestions. I also thank Mr. P. P.Rawal, Mr. B. P. Pati, Mr. Randhava, Mr. Ramkumar, Mr. Amit Kumar, Mr. Sisodiya, DCF's Gir National Park and Sanctuary. My special thanks to Mr. V. J. Rana, ACF, Sasan for his moral support and encouragement. I am thankful to the Range Officers and field staff of Hadala and Jasadhar ranges in Gir east division for their assistance during field work.

I am thankful to Library, Herbarium, Computer & GIS, Research Laboratory, RISO, Account, Store and Administration sections of WII for their support and cooperation.

I am grateful to Kartikeya Singh and Bhabhisa for much needed company in the field. I thank my colleagues Meena and Kausik for their kind cooperation and help in the field data collection. I am thankful to my field assistants Bhupat, Bhola, Kanti and Manu for their sincerity and hard work in the field.

I thank residents of Dodhi, Asundrali, Leria, Khajuri, Mindha, Ghudjinjwa, Hadala and Tulsishyam for their cooperation in field data collection. My special thanks to Meghabhai and his family for making my stay comfortable at Dodhi for entire duration of fieldwork. I am thankful to Auntie, Bablu, Neelu, and entire family of St. Joseph School, Una for their generous hospitality.

My heartiest gratitude to Bapu, Dr. Jhala, Rajeshwariba and Harshu for entertaining me on odd times and giving me homely atmosphere away from my home. I owe a lot to Bapu for his blessings. His precious prayers contribute a lot to my success.

Sincere thanks to my seniors at WII, Drs. Rashid, Jayapal, Anupam, Basu, Ramesh and Bhaskar for valuable advice and comments. I feel indebt to Rashidbhai for those thought provoking discussions which immensely help learning lots of ecological concepts and theories. I thank Jeewan, Asghar, Sabya, Shirish, Hiten, Vivek, Bibek, Upamanyu, Joseph, Rishi, Bopanna, Gopi, Abhisek, Jagdish, Devendar Chauhan & Thakur, Pankaj, Kamlesh, Darsh, Udayan, Merwyn, Jimmy, Gajju, Kuldeep, Sudhansu, Vinay, Avdhut, Vishal and all current and past MSc students for sharing joys and sorrows during the stay at WII old hostel.

I thank Dr. Anupam, Joseph, Bopanna, Vijay and Bibek for suggestions and proof reading and Rishi for helping in final print-out. I also thank Ambica, Neha and Randeep for their technical help in GIS related issues. I thank Mr. Vinay, PS to Dr. Jhala for his help.

At Ahmedabad, I thank Kamat sir, Dharmendra (Shah & Patel), Jigu, Manish, Kamlesh, Kapil, Vinu for their always welcoming gestures. I feel proud of my friends, without their constant support and love I would have never seen this moment. I also thank Udaybhai Vora, DCF, Gandhinagar for his help in plant identification.

I am grateful to my parents and family for bearing with my free-lancing life for almost a decade without any complaint. I am always in need of their blessings and love.

I feel indebted to all those teachers who were instrumental in shaping up my career. I pay humble tribute to my teachers by dedicating this thesis to them.

Last but not least, my heartiest thanks to Gir ecosystem for allowing me fullest to enjoy it's mysterious beauty in different moods.

List of Tables

List of Figures

Abstract

I studied the ecology of chital (*Axis axis)* and their ecological interface with sympatric livestock in Gir National Park and Wildlife Sanctuary from March 2004 to May 2006. Impact of sympatric livestock on chital was assessed by a) response of demographic characteristics like density, group sizes and body condition of chital b) controlling the confounding effects of environmental variability, a detailed comparative study of i) activity and ranging patterns, ii) habitat use and selection patterns, iii) seasonal food and foraging patterns of chital and livestock was conducted to evaluate resource use and overlap c) long term impacts of livestock on the habitat were assessed by exclosure studies and vegetation sampling along radiating transects from *Ness* sites.

Data generated were used to test the following hypothesis and predictions: If competition with livestock were a limiting factor for chital, then

1) Chital should have lower densities, smaller group sizes and poor body condition in areas sympatric with livestock.
2) Diet and habitat use by chital should be similar with a high degree of overlap with livestock for them to potentially compete.
3) Livestock use of an area should reduce forage availability of chital and impact vegetation communities especially regeneration and density of shrubs and trees.

During winter (Dec. 2005 to Feb. 2006), 82 systematic foot transects (231 km) were sampled in 36 forest blocks within the Gir protected area. The density ($\hat{D}$ ± se) of chital in Gir was estimated 44.77 ± 7.1 km^{-2} followed by sambar (*Cervus unicolor*) (2.86 ± 0.81) and nilgai (*Boselaphus tragocamelus)* (1.16 ± 0.47), while total wild ungulate density was 48.3 (± 6.1) km^{-2}. Realized rate of increase '*r*' were estimated to be 0.071 ($p \leq 0.001$ $R^2 = 0.90$) and 0.0705 ($p \leq 0.05$, $R^2 = 0.87$) for chital and sambar respectively. Average and typical group sizes were 7.1 ± 0.8 and 18.5 for chital; 1.7 ± 0.2 and 2.43 for sambar; and 2.5 ± 0.6 and 4.11 for nilgai.

There was no difference between areas with and without livestock for chital or wild ungulate densities, group sizes or body condition scores (Hotelling's *t* test, $t = 6.4$, $p = 0.17$) at the landscape scale. Instead chital

density and wild ungulate density were correlated with rainfall (r = 0.92, p = 0.08). At site specific scale, summer chital densities were higher in areas devoid of livestock (t test, t = 2.75 p ≤ 0.05). Group sizes and body condition of chital were similar between areas devoid of and sympatric with livestock.

There were two foraging peaks observed in all seasons for both chital and livestock, and these peaks were rather diffused in monsoon. Both, chital (1.97 ± 0.17 km) and livestock (6.35 ± 0.39 km) travelled more during summer compared to winter and monsoon. Habitat preference for foraging by chital was *Acacia-Ziziphus* > Riverine > *Anogeissus* mixed habitat. Livestock's habitat preference for foraging was *Boswelia-Lannea-Terminalia* > *Acacia-Ziziphus* > *Anogeissus* mixed > Riverine habitat.

A total of 106 different food items of 100 plant species were eaten by chital (68), cattle (74) and buffalo (75). Annual diet (dry biomass) of chital was largely composed of various browse items (74 %); whereas forbs and grasses contributed more than 70 % of annual diets of livestock. Browse items were consistently higher in crude protein and lower in ash compared to grasses. Mineral contents in major food items remained relatively high during monsoon. Chital had broader niche breadth (Levin's measure D = 0.33) compared to cattle (0.20) and buffalo (0.16). Maximum dietary overlap between chital-buffalo (48.0 %) and chital-cattle (43 %) was during summer. Livestock foraged in areas with abundant food to minimize foraging time while chital foraged in areas with low biomass but high nutrient quality.

Densities of browse tree (One-way ANOVA, F= 6.74, p ≤ 0.001)and shrubs (K-W ANOVA, χ^2= 8.49, p≤ 0.05) were higher in areas with sympatric livestock, while sapling density and percent ground cover were not not different between areas sympatric with livestock and devoid of livestock. Low to moderate intensity of livestock grazing seemed to improve percent cover of palatable annuals at the cost of coarse perennials. Chital pellet abundance was higher at low intensity of livestock grazing compared to areas devoid of livestock (Man Whitney U test, Z = 3.8, p ≤ 0.001). Abundance of other wild ungulates pellets was low only in moderate livestock use category of active *Ness* (Man Whitney U test, Z = 3.45, p ≤ 0.001).

In conclusion, I did not find detrimental effect of livestock in the short term or long term i.e. there were no differences in group sizes and body

condition of chital nor were there any trends in vegetation in areas sympatric with livestock. However, chital densities were depressed to some extent in areas sympatric with livestock. The current stocking density of livestock (31 km $^{-2}$) seems to have little impact on chital ecology and habitat of Gir. Reduction of above ground biomass was observed only in the vicinity of *Ness* sites (>500m). By a management strategy of controlling stocking density of livestock and by rotating *Ness* locations every 3-5 years would further reduce this negative impact.

CHAPTER 1

Introduction

The most meaningful definition of ecology from the conservation point of view could be '*the discipline of science that underpins the technology of conservation*' which was given by Harper (1987). An understanding of the ecology is important for the conservation of 'species of interest' in particular and the natural system; as a whole. The fundamental ecological questions like, 'Could we more easily conserve some species by eliminating pests or competitors…' can be answered only by an in-depth knowledge of ecology of the system in which the target species inhabits.

Keeping this ecological background in mind, some ecological aspects of chital (*Axis axis*) were studied in Gir National Park and Wildlife Sanctuary, India. Chital (*Axis axis*) is an endemic medium size cervid which is capable of achieving high densities and due to its wide distribution it forms the most important prey base for large carnivores. Since chital densities and abundance shape the composition, structure and densities of higher trophic levels, it can be considered as a keystone species in most of the forested ecosystems of India.

1.1 Status, Taxonomy and Distribution

Chital (*Axis axis*) is categorized as a 'least concerned' species according to IUCN Red Data List, 2006 and schedule III species according to Wildlife Protection Act,1972 (Govt. of India, 1972).

The classification of Chital *(Axis axis)* according to Mitchell (1982) and Myers *et al*. (2006) is as follow:

Order:	*Artiodactyla*
Suborder:	*Ruminantia*
Family:	*Cervidae*
Subfamily:	*Cervinae*
Genus:	*Axis*
Species:	*axis*

The whole set of ungulates arose from the early mammalian stock at the start of the Cenozoic era some 60 million years ago, many of which became extinct and are now represented by almost 200 species (Mitchell, 1982). The order *Artiodactyla* (even-toed ungulates) originated 36-38 million years ago during Eocene epoch (Halls, 1984). All ungulates are mainly herbivorous in diet. They are classified into two orders i.e. *Artiodactyla* (even-toed ungulates) and *Perrisodactyla* (odd-toed ungulates). The even-toed species are more diverse and have proved to be better survivors, and compose almost all the medium to large size herbivores of the world (Mitchell, 1982).

Among Artiodactyls, suborder *Ruminantia* is very diverse and it includes five families. The ruminants play a significant role in shaping various terrestrial ecosystems which they occupy. They are specially adapted to facilitate the fast intake of coarse food items and better digestion of semi-digestible plant cell wall material. The very adaptation is facilitated by the replacement of front teeth in the upper jaw by a horny pad and presence of a four chambered stomach.

The family *Cervidae* includes all antler bearing ruminants, commonly known as 'deer'. The family is further classified into three subfamilies, among these three, *Cervinae* comprises 9 genus and 28 species, mostly of Eurasian origin. The chital is classified under genus *Axis*, which includes four species, of which two occur in India, the hog deer (*Axis porcinus*) and chital *(Axis axis)*. Chital has reported to have two subspecies, one from India (*A. axis axis* Erxeleben, 1777) and another from Sri Lanka (*A. axis ceylonensis*, Fisher, 1829) (Ellerman & Morrison-Scott, 1951).

The distribution of Chital (*Axis axis*) in their native range is described by Schaller (1967). The distribution is sporadic throughout the Indian subcontinent from Himalayas in the north to Kerala and Tamil Nadu in the south and western Assam and Sikkim in east to the Gir forests in the western most state of the country. Chital was once widely distributed in Pakistan but went extinct due to rampant hunting and poaching (Roberts, 1997). Being a very adaptive species, it occurs in a variety of forest vegetation types, from dry thorn forests to moist and evergreen forests as well as mangrove swamps of the Sunderbans. Because of it's adaptation for a wider ecological and habitat diversity, chital was successfully introduced to other continents and most of them have naturalized now in their new ranges. The introduced population of chital occurs in some republics of former USSR, Brazil, Argentina, Uruguay, USA, Australia, Hawaii and several fenced private ranches in South Africa (Lever, 1985).

In most of the Indian forests chital plays a keystone species role by attaining higher densities and constituting substantial proportion of large carnivore diets. Karanth & Sunquist (1992) reported 51 chital per km^2 in moist deciduous forests of Nagarhole National Park. In another study Karanth & Nicholas (2000) estimated 49.7 and 51.3 chital per km^2 in deciduous forests of Kanha and Pench. Similarly, Khan *et al*. (1996) estimated 50.8 chital per km^2 in dry deciduous forests of Gir. In a previous study, Mathur (1991) reported a very high abundance of chital (>100 individuals/ km^2) in Kanha National Park which shows that chital can attain higher densities in favorable ecological conditions.

1.2 Origin of the work

After declaring Gir forests a Sanctuary in 1965, three major ecological studies were carried out in Gir by Hodd (1969), Joslin (1973) and Berwick (1974) which were followed by several managerial inputs like removal of Pastoralist settlements and creating a national park of 256 km^2 in the core of the protected area. Unfortunately, the resultant ecological change in the ecosystem was not simultaneously monitored on a long term basis. After a long pause, in 1986, the Wildlife Institute of India initiated the Gir Lion Project in collaboration with Gujarat Forest Department. The study was aimed to evaluate the past management inputs and to study the status of prey and predator species (Chellam, 1993; Khan, 1993)

In the late nineties, GEF- India Eco-development project was launched to facilitate the conservation and management of the Asiatic lions and their last home i.e. Gir National Park and Sanctuary. To evaluate the impacts of this project on Gir Ecosystem, the Wildlife Institute of India and Gujarat Forest Department initiated a short term collaborative monitoring project. Subsequently, the project 'Ecological Monitoring of Gir' was initiated as an extension of the previous one for long term monitoring of lion, ungulates, livestock and vegetation. The present thesis covers certain aspects of ungulate, livestock and vegetation studies as part of the above mentioned project.

1.3 Aim of the study

Most of the natural ranges of chital are shared with livestock. Hence, in this context, the ecological interface between chital and livestock (cattle and buffalos) is required to be addressed for better understanding of chital ecology and eventually help in designing conservation and management strategies pertaining to livestock regulation and habitat manipulation. Therefore a systematic effort was made to evaluate the direct as well as the indirect impact of sympatric livestock grazing on the ecology of chital population. Direct negative impact of livestock grazing was thought to be reflected in population performance of chital; and therefore different aspects of chital

ecology i.e. population demography; activity and ranging patterns; habitat use and selection patterns; as well food habits were studied.

Indirect negative impacts, as described by Mackie (1978), include: 1) gradual reduction of vigour of some plants and in the quantity and quality of the forage produced; 2) elimination or reduction of the ability of forage plants to reproduce or regenerate; 3) reduction or elimination of locally important cover types and replacement by less favourable types or community, either by direct action or by changing the rate of natural succession process; 4) general alterations and reduction in the kinds, qualities and through selective grazing or browsing or other activities.

Chital is a plastic species capable of considerable adaptive response (Ables, 1977). This characteristic is well reflected through its wide-ranging distribution in India and even where it is an exotic. But recently due to a rapid shrinking of habitat, wildlife populations in India have been greatly reduced. But chital is still widespread and common in India, especially in protected areas.

Chital can be compared with white tailed deer *(Odocoileus virginianus)* of America due to their abundance and widespread distribution in the Indian subcontinent. But unfortunately it has received very little scientific attention in their native range. The ecological information on chital is very sparse and very few ecological studies solely focused on chital are available.

Livestock grazing is especially widespread and livestock holding form an important component of agricultural economy in our country (Mishra, 2001). A rapid industrialization and change in traditional land use pattern following the population explosion in India, has taken a big toll on traditional grazing pastures and unprotected forests. In the case of Gir, the forest cover had declined from 3100 km^2 at the turn of the 20^{th} century to 1412 km^2 till it was declared as a Sanctuary (Singh & Kamboj, 1996). As a consequence of rapid disappearance of pasturelands, a large population of livestock nowadays thrives on protected forest areas. Resident *Maldhari* (a local occupational tribe who practices animal husbandry) and their livestock are considered an important management problem in Gir. There are 54 *Maldhari 'Nesses'* i.e. hamlets having a total of 350 households. Out of 1412.13 km^2 of sanctuary area 52 km^2 is occupied by 14 forest settlement villages

(permanent human habitation with cultivable lands –administered by forest department), which harbor more than 4000 cattle and buffalos (Singh & Kamboj, 1996). *Maldharis* and the forest settlement villagers have legal access to the sanctuary area for livestock grazing and fuel wood collection.

Gir is an island of intact forest dotted with several *Maldhari* settlements and surrounded by almost hundred revenue villages within a buffer of six kilometers from the sanctuary border. The livelihood of the village community is based on agriculture and animal husbandry. Hence, the human encroachment on forestland and forest resource use would result in deterioration of wildlife habitat. Chital, which is believed to be a grazer by choice (Ables, 1977), likely competes for food most acutely with the livestock. Therefore, an in-depth study on the ecology and resource use by chital and sympatric livestock is essential.

Effect of livestock grazing is a critical issue, which has been seriously debated in last few years (see Saberwal, 1996; Mishra & Rawat, 1998; Saberwal, 1998). Removal of *Maldhari* livestock needs to be based on scientific evidences of their detrimental impact on wild ungulate populations and habitats. To minimize the impact, Khan (1995) suggested regulating the livestock heads per settlement and relocation of *Maldhari* from valleys and riverine forests to reduce the intensive localized impact and to attain the uniform grazing in the sanctuary area. The debate on whether local human use of wildlife reserves should be modified, curtailed or encouraged continues to be fuelled by activism rather than by ecology (Mishra & Rawat, 1998). The present study is an effort to understand the interface between wild and domestic ungulates in Gir.

Since chital contributes a significantly large portion to the lion's diet in Gir (Chellam, 1993; Joslin, 1973), better management practices that enhance chital density and population are likely to be beneficial for lion conservation. Realizing the importance of chital population as a keystone species in the Gir ecosystem, it is essential to monitor population density (Khan *et al.* 1996; Khan & Vohra, 1992), demographic parameters (Schaller, 1967), nutritional condition (Riney, 1960) and behavioral adaptability. Another important ecological aspect relevant to the conservation and management of Gir is the potential negative impact of sympatric livestock grazing on chital population.

In this perspective it is essential to study the potential for competition between chital and livestock for food and habitat resources.

One of the most crucial of Weins' (1989) criteria for detection of competition in the field is that one or more species can be shown to be negatively affected by the interspecific interactions. The information on population performance i.e. densities, group sizes and body condition of chital is critical to understand and evaluate the negative impact, if any, of livestock grazing on chital. On comparison of such information obtained from areas sympatric with livestock grazing and devoid of livestock can help in understanding the interface between chital and livestock.

On one side, intensive and unregulated livestock grazing seems to be detrimental to the natural community structure of vegetation and might cause the invasion of unpalatable floral species (Moseley & Crawford, 1995). On other side, moderate livestock grazing may be helpful in maintaining ideal habitats for ungulates in high graminoid biomass condition, as cattle and buffalo could potentially facilitate smaller herbivore species (McNaughton, 1979; Prins & Olff, 1998). The lopping of trees helps by checking the browse line so that it remains within the reach of most ungulates (Khan, 1994). Beside that, intermediate disturbance could potentially favors the growth of highly palatable *Acacia* and *Ziziphus* species. Similarly moderate grazing creates the optimal grass condition for chital (Schaller, 1967; Khan, 1994).

By comparing data on vegetation composition and quantity between areas intensively used by livestock and devoid of livestock can help in understanding the ecological consequences of sympatric livestock grazing on forestlands. Also, the information on food habits, diet niche overlap and habitat use of chital and livestock can provide insight into the mechanism of coexistence, facilitation or competition between these two groups of animals.

1.4 Review of Literature

Gir is synonymous with Asiatic lions (*Panthera leo pesica*) and hence it is obvious that research works carried out so far in Gir were mostly oriented to Asiatic lions (Joslin, 1973; Sinha, 1987; Chellam, 1993; Singh, 1997 etc.). However, several studies attempted to study wild ungulates and their habitat components in Gir (Hodd, 1970; Berwick, 1974; Khan, 1993; Sharma, 1995).

Ungulates, as being the primary consumers, play an important role in sustenance of higher trophic levels in an ecosystem. Ungulates form the major bulk of prey base for large carnivores in different protected areas of the country (Schaller (1967) in Kanha National Park, Johnsingh, (1983), Karanth & Sunquist (1995) in Nagarhole National Park, Ramakrishnan *et al* (1999) in Kalakad-Mundanthurai Tiger Reserve and Biswas & Sankar (2002) in Pench Tiger Reserve). The bulk of wild ungulate density in Indian forests is contributed by chital (Khan, 1995; Sankar, 1994; Karanth & Nicholas, 2002; Bagchi *et al*, 2003); and therefore, chital is a keystone species which determines large carnivore density, community and structure.

Among all cervids in India, chital is widespread in their native range as well as abundant in exotic condition and therefore it has acquired scientific attention. First scientific efforts to study the ecological aspects of chital ecology were made by de Rames & Spillet (1966) in Corbett National Park, in India and Graff & Nichols (1966) in Hawaii followed by Schaller (1967) in Kanha National Park, Berwick (1974) in Gir National Park, Ables (1977) in Texas, Shrestha (1982) in Nepal, Bhat (1993) in Rajaji National Park, Khan (1993) in Gir National Park, Shankar Raman (1997) in Guindy National Park, Bagchi (2001) in Ranthambhore National Park.

1.4.1 Density, Demography and Dynamics

A major constraint in conserving and managing the large mammal species is the lack of quantitative information on the abundance, distribution and habitat requirement of these species, which is very essential for the assessment of current management practices. According to Renecker & Hudson (1993), those species attain higher densities and usually form groups to protect themselves against predators and can exploit higher productivity of open habitats. Chital fits this category as it is found generally in open forests and forest edges (Graff & Nichols, 1966; Schaller, 1967).

For effective lion conservation, understanding of prey-predator relationship is essential. Chital contributes significantly to the wild prey base of lion in Gir, compared to other ungulates (Joslin, 1973; Chellam, 1993). According to Khan (1995) and Khan *et al* (1996), total ungulate estimation was around 55,000 of which chital counted around 51,000.

Realizing the importance of the chital population as an important prey species, several attempts have been made to estimate population density of chital and other ungulates in Gir (Joslin, 1973; Berwick, 1974; Chellam, 1993; Khan, 1993; Goyal *et al*. 2004).

But a single estimate of population size at one point in space and time has limited values for the conservation and management of wildlife populations. The very interest of wildlife conservation and management lies in understanding the 'population trends', which is being defined as a statistic reflecting average direction and magnitude of change over a specified period of time (Droege, 1990). The annual change in abundance or density of a wildlife population is described as the rate of increase (Hone, 1999). Aspects of the estimation of the rate of increase and biases have been explored by many authors (Caughley & Birch, 1971; Harris 1986; Eberhardt, 1987; Gerrodette, 1987; Eberhardt & Simons, 1992; Johnson, 1994). The rate of increase is computed by using demographic parameters (birth and death rates) (Caughley, 1976; Johnson, 1994; Sibly & Smith, 1998) and/or from the numerical response (Caughley, 1976, 1980).

Ungulates commonly experience considerable seasonal, climatic and spatial variations in resources, especially in arid and semi arid tropical environment. Environmental stochasticity and sometimes density dependence play a vital role in herbivore population dynamics in such conditions (Caughley & Gunn, 1993). The study of population dynamics involves the changes that occur over time and the causes of those changes (Johnson, 1994). A very few studies in the subcontinents have been carried out to understand the population dynamics and the demography of chital populations (de Rames & Spillet, 1966, Graff & Nichols, 1966; Schaller, 1967; Sidensticker, 1976; Ables, 1977; Barrette, 1991; Khan & Vohra, 1992; Shankar Raman, 1997).

The group sizes are a function of the social behavior (Jarman, 1974, Wilson, 1975, Clutton-Brock & Harvey, 1978b, Dinerstein, 1980), social and reproductive behaviour (Fuchs, 1977) and food availability (Wilson, 1975; Sharatchndra & Gadgil, 1975, Khan *et al*, 1996). Besides the availability of the food items, the pattern of food item distribution in a foraging area dictates the group sizes in ungulate species (Jarman, 1974; Mishra, 1982; Johnsingh, 1983; Karanth & Sunquist, 1992). Shankar Raman (1997) observed a positive relationship between chital density and rainfall in different habitats. Dinerstein (1980) considered the predation risk as a governing factor in chital group size. The effect of canopy cover on chital group size was shown by Barrette (1991) and Khan *et al* (1995). Chital exhibits open membership social structure and hence group-sizes show diurnal as well as seasonal variations (Sharatchandra & Gadgil, 1975, Barrette, 1991).

Generally in chital a matriarchal family unit comprises of an adult female, her yearling and a fawn. Due to the loose aggregation in chital herd, sometime chital herds are composed of two or more of these family units and can be accompanied by other individuals of mixed sex and age class (Fuchs, 1977). The mixed age and sex groups are frequent in the rutting season (Khan & Vohra, 1992). Two additional associations commonly seen among chital are all-male herds and nursery herds, the latter consisting of only females with fawns (Fuchs, 1977). Tak & Lamba (1984) have observed some herds of over 500 individuals, but smaller groupings are more typical. In India, average monthly herd size varies from 5-38 individuals (Schaller 1967, Khan *et al*, 1995), whereas in Texas 2-15 (Fuchs, 1977) and in Sri Lanka 2-4 individuals (de Silva & de Silva, 1992) were noted. In general, herd stability of axis deer is poor; marked individuals, both male and female, have been observed to change associations frequently, sometimes daily (Schaller, 1967; Fuchs, 1977; Miura, 1981). Thus, the most cohesive unit is that of mother and young (de Silva & de Silva, 1992).

Research on captive ruminants has clearly established the role of nutrition on virtually all aspects of individual and herd productivity, but assessment of nutritional effects on population dynamics of free-ranging ungulates is rare (Cook *et al*, 2005). The use of nutritional indices to assess the well-being of wildlife population has increased substantially recently

(Harder & Kirkpatrick, 1996). Several techniques have been devised and applied to assess the nutritional condition of their management. However, most of these techniques utilize deer trapped (Leader- Williams, 1982) or killed either by natural causes or by shooting (Park & Day, 1942; Cheatum, 1949; Leader-Williams, 1982). A simple noninvasive field technique to assess the physical condition of ungulate was devised by Riney (1960), which involves the scoring of various body parts of an ungulate individual in the field. There is virtually no information on the nutritional condition of ungulate species and subsequent effect on the population dynamics in the Indian subcontinent. Recently, a study on the blackbuck by Priyadarshiny (2005) has attempted to explain the relationship between forage quality, calving frequency and body condition.

1.4.2 Behaviour and activity patterns

Many problems in conservation biology rely on a detailed understanding of species natural history. Behavioral ecological studies verify and quantify these variables and give important information to conservation models (Goss-Custard & Sutherland, 1997). Baseline behavioral and ecological data collected in the course of field studies have the potential to predict a population's response to habitat disturbance (Caro, 1998).

Many previous studies have shown the importance of studying activity patterns of various wildlife species (Green, 1985; Walker, 1957; Newton, 1984; Datta, 1993; Isvaran, 1995). Some studies have that been carried out on chital include Schaller (1967) in India, Graff & Nichols (1966) in Hawaii and Fuchs (1977) in Texas. Apart from this, very little has been done in studying activity pattern and time budget of chital (but see, de Silva & de Silva, 1992; Sharatchandra & Gadgil, 1980; Shrestha, 1982; Bhat, 1993).

Wild ruminants spend most of their day (>90%) foraging, resting/ruminating or walking between bedding and feeding sites (Renecker & Hudson, 1993). The forage quality, distribution and abundance in time and space influence the activity pattern and time investment of ungulates in various activities (Lucas, 1987; Bunnell & Harestad, 1989; Dove, 1996). Spatial distribution of forage affects the ungulate movement for food search which might, in turn, expose them to high predation risk and therefore need to invest more time on vigilance (Owen-Smith, 2002; Caro, 1994). Parker &

Robins (1985) explained the role of ambient temperature on the daily activity patterns of ungulates. The time spent in various activities is influenced by energy requirement and the constraints they encounter i.e. food distribution, predators and thermal stress (Lucas, 1987; Bunnell & Harestad, 1989; Dove, 1996).

Energy demands in animals are indicated by the amount of time spent on foraging (Fancy & White, 1985; Bunnell & Gillingham, 1985). Survival and reproduction depends on how this energy is obtained and time spent (Bunnell & Harestad, 1989). Thus time spent in foraging is an insight into the strategies that animals adopt to survive and reproduce (Bunnell & Gillingham, 1985). Allocation of time spent in foraging by various mammals is influenced by a number of factors such as body size, diet, digestive system capabilities and mode of locomotion (Bunnell & Harestad, 1989).

According to Graff & Nichols (1966), chital avoids being away from forest cover during the heat of the day and when humans are around. They found chital feeding activity in open areas mostly during early morning and late afternoon. In cooler weather, feeding extended over much of the day. de Silva & de Silva (1992) observed in Ruhuna National Park, Sri Lanka, that grazing activity in chital mostly occurred throughout the day, but less during afternoon hours. In Corbett National Park, India, feeding activity of chital peaked at dawn and sunset during the cold as well as hot seasons, with more prolonged peaks in the cold season. However, during the rainy season, feeding was in bouts at various hours presumably because of intermittent rain and/or because food was in abundance (Tak & Lamba 1984). Most studies have noted that rest and rumination occur periodically when not feeding. Major limiting factors in foraging of ruminants is gut fill and passage time which depends on forage quality and reflected by frequency of occurrences and time spent in rumination. Schaller (1967) found chital resting in after midnight until shortly before dawn almost as a routine. On overcast days, axis deer tend to remain more active on grasslands and do not seek the shade of trees during mid-day (Schaller 1967; Tak & Lamba 1984).

1.4.3 Habitat Use

Why an animal occupies a specific habitat or selects a particular food item may reveal much more about the factors that limit a species than simply documenting patterns of use (Gavin, 1991). Understanding deer habitat use is important in predictive management of increasing deer populations and in assessing the potential for inter-specific competition (Hemami *et al*. 2004), particularly between native and introduced species.

Different field techniques have been employed to assess the habitat use by wild animals which include, radio tracking (Johnson, 1980; Thomas & Taylor, 1990; McShea *et al*, 2001) or direct observations (Biggins & Pitcher, 1978, Stinnett & Klebenow, 1986) or indirect evidences like track counts (Litvaitis *et al*, 1985; Thompson *et al*, 1989) and pellet counts (Colins & Urness 1981, Orr & Dodds, 1982).

Extensive information is available on ungulate -habitat association (see Howard, 1982; Van Dyke *et al*. 1983). Habitat selection is strongly influenced by quantity and quality of food (Sinclair, 1975; White, 1978; Duncan, 1983; Murden & Risenhoover, 1993) as well as foraging opportunities (Watkins *et al*. 1991). Several studies have explained the role of different biotic (Lamprey, 1963; Jarman, 1972; Jarman, 1974) and abiotic (Duncan, 1983; McNaughton, 1988, 1990) factors in influencing habitat use pattern of sympatric herbivores in a community. Along with biotic and abiotic factors, the role of morphological and physiological factors in segregation of niches in the herbivore community has also been studied in detail (Hofmann & Stewart, 1972; Hanley, 1982; Jarman, 1974; Demment & Van Soest, 1985).

Although, several extensive studies on forest ungulates have mentioned broad habitat use of chital (Schaller, 1967; Berwick, 1974; Eisenberg, 1981; Tak & Lamba, 1984; Mishra, 1982; Khan, 1993), virtually no information on the detailed habitat use and selection patterns of chital is available (but see, Bhat & Rawat, 1995; Bagchi *et al*. 2003). Similarly, very little information is available on broad habitat use patterns of chital in exotic condition (Graff & Nichols, 1966; Ables, 1977). Available information on habitat use by chital, categorize it as a generalist forest dwelling species which occupies forest edges and ecotone zones between forest and grassland (Berwick, 1974; Schaller, 1967; Bagchi *et al*, 2003).

1.4.4 Food Habits

The knowledge of the feeding habits of wild animals is critical to effective wildlife management and many phases of ecological research (Talbot & Talbot, 1962). Beside that the studies of food habits have intrinsic value because they are important components of an animal's life history (Litvaitis *et al*, 1996) and substantial information has been collected on the diets of many terrestrial vertebrates in Africa (eg. Talbot & Talbot, 1962; Gwynne & Bell, 1968; Leuthold, 1977; Bell, 1971; Jarman & Sinclair, 1979) in North America (Martin *et al*. 1961; Tueller, 1979) and Europe (Jackson, 1974; Putman *et al*, 1993; Mann, 1983; Mann & Putman, 1989).

Research on food habits of different herbivores has not progressed in India as compared to other countries. Schaller (1967) has listed the food plants of wild ungulates and cattle. Green (1985) has studied the ungulate food habits in Kedarnath Wildlife Sanctuary by faecal analysis. Haque (1990) studied wild ungulate food habits by direct observation of animals feeding and by pellet analysis. Johnsingh & Sankar (1991) studied the food plants of wild ungulates and cattle in Mundanthurai while, Berwick (1974) and Khan (1994) studied the food habits of the ungulates in dry tropical forest of Gir, these studies were mostly based on opportunistic direct observations.

Rodgers (1988) has categorized chital as a generalist feeder, which takes grass, forbs and woody plants in its diet. While, Hoffmann (1985) classified chital as an intermediate/mixed feeder on the basis of morpho-physiological ruminant feeding types. According to Schaller (1967) and Chaudhary (1972) chital forage on both grass and browse items, with grass providing the bulk of their diet in all seasons. Due to chital's preference for grass, it is believed to compete closely with livestock for food (Ables, 1977).

Very few studies have focused on the food habits of livestock and subsequent impact on forest and grassland (but see, Uresk, 1986; Putman *et al*. 1984; Hansen, 1976; Hunter, 1962). Several studies have examined the dietary niche overlap between wild and domestic ungulates (Mackie, 1970; Hansen & Reid, 1975; Hansen *et al*. 1977) and subsequent impact on wild ungulates (Rhodes & Sharrow, 1990; Ghosh *et al*. 1987).

The scientific management of ungulates is based on the understanding of their food availability and preferences, the nutritive requirements of an

animal unit, and the value of natural feeds towards meeting these requirements (Thompson *et al*. 1973). Of all factors affecting wildlife production, supply and maintenance of quality forage is perhaps the most challenging one to the wildlife managers (Hanson & Smith, 1968). According to Dietz (1968), the measures of forage quality are palatability, nutritive composition and digestibility, gross and digestible energy, and ruminal end products. Among all chemical constituents of ruminant diet crude protein is considered the most important nutrient (Morrison, 1957). Three fourth of the dry weight of plant material eaten by herbivores is composed of carbohydrates, which includes sugars, starch, cellulose, gums and related substances (Dietz, 1968). Ruminants are not dependent upon fat in the diet, because fatty acids can be synthesized in the rumen from carbohydrates and protein (Dietz, 1968). Among minerals, calcium and phosphorus comprise about 90% of mineral content of the skeletons of ruminants. Calcium is the important constituents of blood plasma while Phosphorus is vital in many body processes (Anderson, 1953; Morrison, 1957). Other minerals- sodium, potassium and magnesium along with zinc, cobalt, copper, iron etc. are necessary for many physioloical processes (Dietz, 1968).

The nutrient contents of various food items are studied by Gosz *et al*. (1972), Robbins & Moen (1975), Short (1975), Short *et al*. (1974 & 1976), Smith *et al*. (1956), Urness *et al*. (1975) and Urness (1969) for various ruminants, mostly cervids. The only study on nutritional compositions of some selected browse species of chital was carried out by Sukh Dev (1978) in FRI Deer Park and he found out that digestible crude protein content in browse items was lower and crude fat and nitrogen free extract were higher in all browse items compared to results from digestion trials by Forbes *et al*. (1941).

1.4.5 Livestock Grazing on Forestland

The presence of high densities of free ranging cattle in the forest lands of India have already been commented on. Many authors draw attentions to the deleterious effects of livestock grazing and associated lopping of trees on forest parameters such as canopy cover, ground cover, regeneration and wildlife density (Saharia, 1984; Ram Prasad & Bhatnagar, 1988; Lal, 1989). Most wildlife protected areas in India support various forms of land use such as agriculture, livestock grazing and collection of minor forest produces

(Mishra, 2001). Kothari *et al*. (1989) report livestock grazing in as many as 73 % wildlife sanctuary and 39 % National Parks in India (of the 101 and 14 surveyed protected areas respectively in those categories) with livestock densities up to 150 per sq km.

Despite such widespread concern for these ecological pressures, there has been little quantification and documentation of cattle activity in forests (Sankar, 1994; Chimere *et al*, 1986; Ram Prasad & Bhatnagar, 1988; Rodgers, 1990, Rollinson *et al*.1956; Mathur, 1991; Silori & Mishra, 2001). Even recent reviews (Sankar, 1994) indicate a remarkable worldwide scarcity of information on competition between livestock and ungulates. There is a dearth of information on density, herding strategy, distance traveled, activity patterns and feeding ecology of livestock in forestlands of the country (Sankar, 1994). When human habitation and large mammal habitats are interspersed with each other, as is the case in most Indian wildlife reserves, conflicts between humans and wildlife are unavoidable (Mishra, 2001).

Livestock grazing has some obvious impact on local ecological parameters. As explained by Huismann (1997) 'species populations are believed to often compete indirectly through their effects on resource availability, rather than by directly preventing each other from accessing the resource i.e. competition often occurs when the amount of resource availability for species gets reduced due to resource use by another. Several studies show the significant impact created by livestock on forest ecology (Cohen *et al*. 1989b; Rodgers, 1990; Shea *et al.* 1990; Sankar, 1994; Berwick, 1974; Mihsra, 2001, Chimere *et al*.1986).

Although the influence of domestic herbivores, particularly cattle, on free ranging wild ungulates has been studied in North America and Europe (Schwartz & Ellis, 1981; Osborne 1984; Wallace & Krausman, 1987; Gordon & Illius, 1988; Yeo *et al*, 1993), interactions between sympatric wild and domestic ungulates have not been examined in detail. Recent reviews indicate a remarkable worldwide scarcity of information on competition between these two groups of herbivores. However, some of the studies have shown concerns on the impact of livestock grazing on ungulates in India (Mathur, 1991; Silori & Mishra, 2001).

Berwick (1974) did not record any competition between wild ungulates and domestic livestock. He also mentioned that wild prey would not increase if domestic livestock were removed to alleviate overgrazing, since wild and domestic preys do not eat the same forage. From the time of Berwick (1974) till date (Khan, 1993; Singh & Kamboj, 1996) wild ungulate densities have increased several folds. Simultaneously, there has been a reduction in the total livestock population in Gir due to the creation of a national park and removal of some resident *Nesses.* Khan (1993) observed a remarkable increase in wild ungulate population and he reported that wild ungulate community contributes 37.1 % and 11.2 % to the total large herbivore biomass in sanctuary west and sanctuary east respectively. This proportion was as low as 11% biomass contribution by wild ungulate community to the overall ungulate biomass of Gir in 1970 as estimated by Berwick (1974). However, it would be not possible to attribute this increase in wild ungulate population to anyone of these following competing hypothesis a) due to decreased competition with livestock by removal of excessive livestock population after creation of National Park b) as a result of increased under story productivity as a consequence of the cyclone of 1983 c) as a result of stricter effective protection from poaching/ hunting for commercial and subsistence purposes.

1.5 Study Area

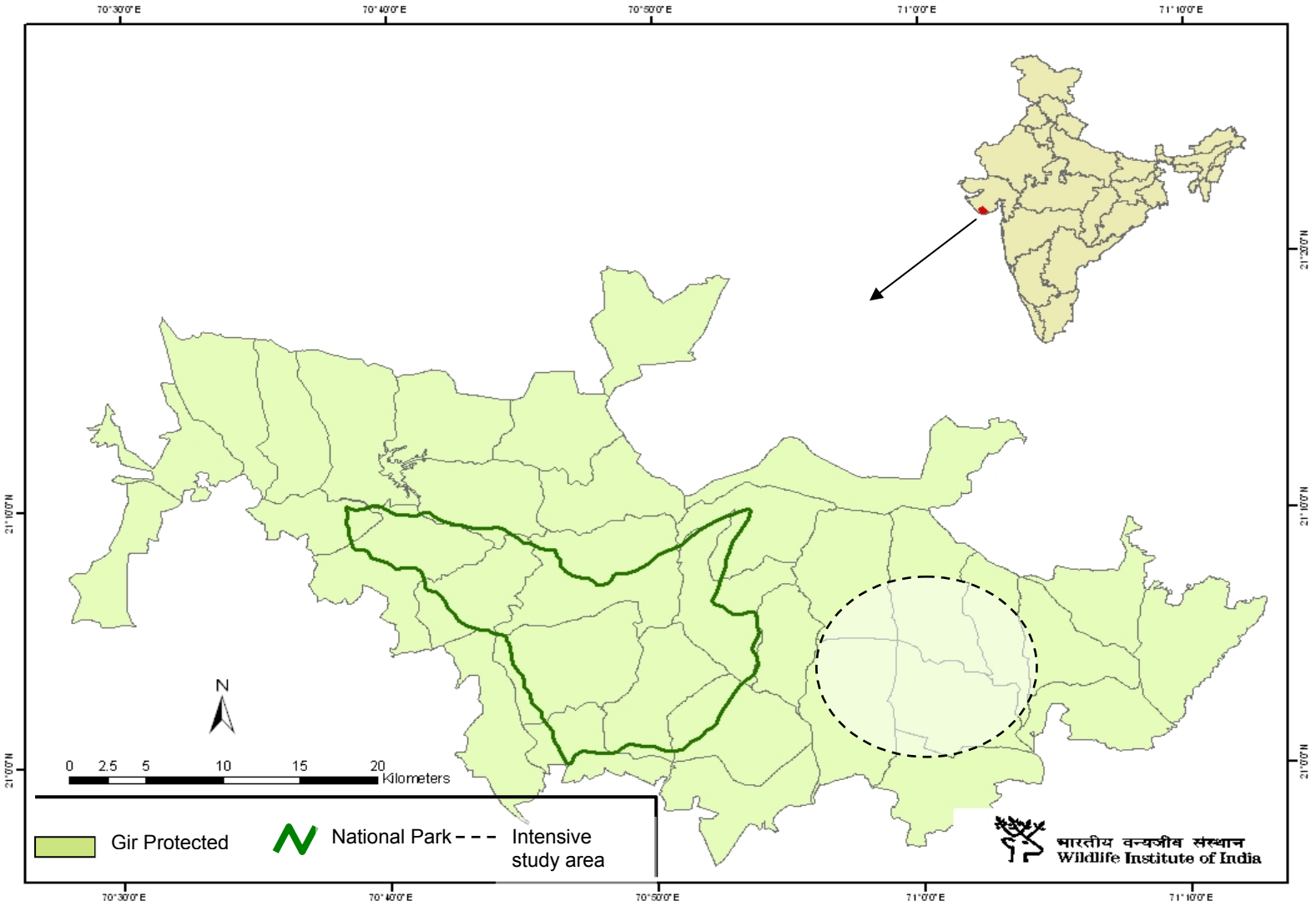
Gir is one of the globally acclaimed high priority conservation areas, supporting last surviving population of rare and endangered Asiatic lion. Besides, it also supports enormous faunal and floral diversity. The Gir protected area is situated in the western most state of India, Gujarat.

1.5.1 History, Location and Size

In general, 'Gir forest' term is used synonymously with the Gir National Park and Wildlife Sanctuary, but the ecological boundaries of Gir couple of centuries before covered half of the Saurashtra peninsula (Singh & Kamboj, 1996). Gir National Park and Wildlife Sanctuary lies between 21^0 20' N to 20^0 40' N and 70^0 30' E 71^0 15' E. The total area under protection as sanctuary (1153.42 km^2) and National Park (258.71 km^2) is 1412.13 km^2 (Figure- 1.1).

The Gir protected area is divided into three management zones viz. Sanctuary west, Sanctuary East and National Park. Due to a rainfall gradient increasing from east to west, these three zones differ ecologically which reflects in the vegetation types (Qureshi & Shah, 2004) and associated productivity. Gir is located about 50 km from Junagadh in south west and 75 km from Amreli in south east, head quarters of adjacent districts. The coast line is 25 to 50 km away from southern park boundary. Over the past 100 years the Gir has been reduced to about a third of it's former size and the PA covers most of the extant forests (Govt. of Gujarat, 1975). In a previous study, Santapau & Raizada (1956) estimated around 2560 km^2 area under forest cover which was significantly contributed by the revenue forests. Later, Joslin (1973) reported 87% decline in forest cover outside the sanctuary area between 1872 and 1969, mostly for cultivation purpose. Uncontrolled commercial exploitation of forest resources and increasing demand for cultivation land by the expansion of human settlement in last two centuries led to continuous decline in the area under the forest cover. It was not until 1920 that a small portion of Gir forest (Dewalia Block) declared as a lion sanctuary by then Nawab of Juagadh. After independence, in 1965, the Government of Gujarat constituted the Gir Wildlife Sanctuary and later it was expanded in 1974 to present size of the PA. Subsequently, a tract of land nearly 150 km^2 was declared as a national park in 1975 and enlarged to it's present size in 1978.

Figure-1.1: Map of Gir National Park and Wildlife Sanctuary in western most state of India –Gujarat.



1.5.2 Topography

The physiography of Gir includes the undulating terrain with rolling hills of low to moderate height traversed with several perennial rivers and streams. The altitude ranges from 100 m MSL to 648 m (Sarakala hill on the northern boundary of Gir PA. The terrain includes plateaus such as Vanasali and Jinjudi and plains such as Hadala, Jasadhar, Kardapan, Janvadla and Dabhala. The drainage is mostly from North to South and the PA is split up by watershed from which stream run to all points of compass and feed the six major rivers viz. Hiran, Singawada, Machhundri, Jatardi, Ghodawadi and Rawal. These rivers have a perennial supply of water and it is the abundant supply of water and grazing pasture that have made the Gir reserve as the centre of cattle rearing. The flow of river is southward in most cases, which has made southern fringe of the Gir, the most irrigated and productive tract of the Saurashtra peninsula.

1.5.3 Geology and Soil

The formation of the hills consists of traps (basalt) of varying composition associated with granite and gneiss, overlaid by beds of calcareous sandstones, which in part assumes the nature of limestone (Santapau & Raizada, 1956). In the Gir, soil ranges from lateritic in the northern and eastern parts to black cotton in the southeast and along many of the plains. The local variations are erosion; deposition and the effect of vegetation cover have introduced many other changes, resulting in the formation of a number of intermediate types (Puri *et al*, 1983). The black cotton soil, in the bottom land is the most common and suitable for dry land agriculture, as it retains moisture for a long (Wynter Blyth, 1962). The red-brown soil originates from rock weathering and is found in the hills, it is poor for agriculture as it is rich in iron.

1.5.4 Climate, Seasons and Rainfall

According to Koppen's (1931) classification, the area comes under 'Tropical Savanna' climate. As a whole it is hot and humid during and after monsoon season. Rainfall is brought by south-westerly winds from Arabian Sea during monsoon season between June and September. There is a distinct dry spell in winter but pretty heavy dewfall is common.

The area experiences three distinct seasons as the other part of the country. There is cool dry winter in Gir from December to March (average minimum temperature 9 ^{0}C.) followed by a hot dry season (average maximum temperature 42^{0}C), which lasts until mid-June. The monsoon breaks in June and continues till September and is followed by a dry post monsoon season till mid-December.

The average rainfall based on the past 28 years data from the western part of the sanctuary and 10 years data from the eastern part of the sanctuary are approximately 1000 mm and 800 mm, respectively (Khan *et al*, 1996). The rainfall gradient increases from east (850 mm at Jasadhar) to west (1000 mm at Sasan). However, the annual variation in rainfall is large. About 94 % of the rainfall is received during monsoon, with July – August being the maximum rainy months. On an average there are 40 rainy days in a year. Long dry spell during monsoon is common. Moreover, the area is roughly affected by a 4 year drought cycle.

1.5.5 Vegetation

The floral wealth of the Gir forest includes some 500 flowering plant taxa (Singh & Kamboj, 1996). Gir comprises one of the largest compact tract of dry deciduous forest, which falls under the 5A/C1b biogeographic subtype (Champion & Seth, 1968). The following broad six subtypes are found in the Gir (Desai, 1972):

1) Open teak forest: This is confined to the red soil in hilly areas. The trees are about 10 m high. The canopy consists of 70-90 % of aged moderate and croocked teak trees and their associates.
2) Open mixed deciduous forest: This type is confined to red yellow soil on hill slopes, where the rain fall is less than 25 inches. Teak is absent in this forest type.
3) Closed teak forest: This is found on gentle slopes with black cotton soil. The trees reach a height of about 15 m and teak forms 60 % of vegetation
4) Thorny forest: The canopy consists of 70 % *Acacia nilotica* of 4 to 6 m height.
5) Dry tropical riverine forest: This type is restricted to perennial and semi perennial streams. The canopy is dominated by evergreen species like

jamun *Syzygium cumini* and karanj *Pongamia glabra*, which rise to a height of 25 m

6) Hill tops: The hilltops are open and dominated by grasses such a *Sehima nervosum* and *Heteropogon contortus*.

The open teak occupies the northwestern region. The closed teak occupies the central and southern portion of the forest while, the open and mixed deciduous forest is found in the eastern region of Gir. Figure – 2.2 shows the four broad habitats in Gir forests, namely 1) mixed & moist mixed vegetation, 2) hill forests, 3) thorn forest, and 4) open scrubland & savanna (Qureshi & Shah, 2004).

1.5.6 Fauna

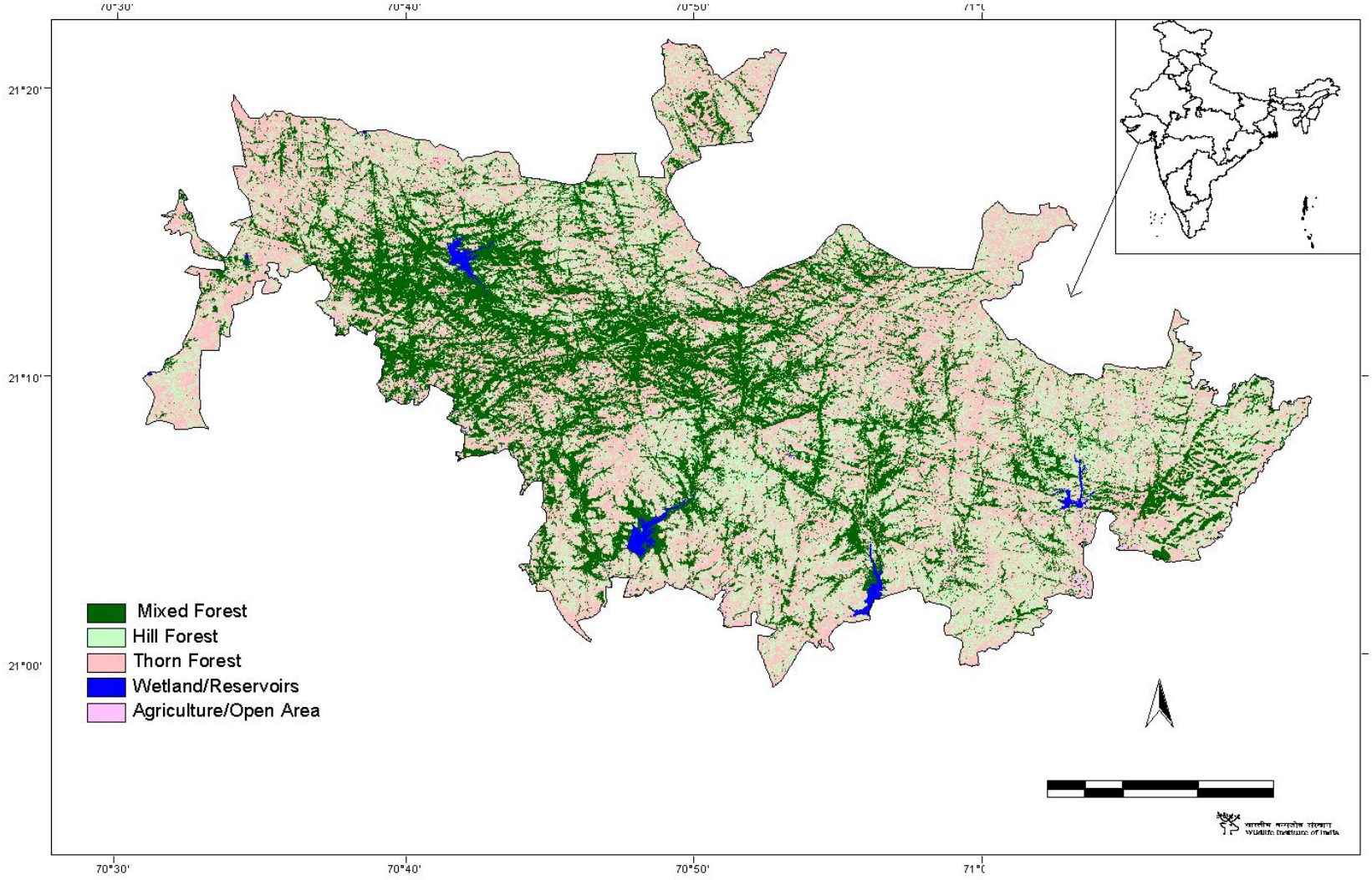
The Gir ecosystem supports about 32 species of mammals, more than 300 species of birds, 26 species of reptiles and more than 2000 species of insects.

The carnivores, among major mammalian fauna include Lion *(Panthera leo persica)*, Leopard *(Panthera pardus)*, Striped hyena *(Hyaena hyaena)*, Jackal *(Canis aureus)*, Indian fox *(Vulpes benghalensis)*, Jungle cat *(Felis chaos)* Ratel *(Mallivora capensis)*, Rusty spotted cat *(Felis rubiginosa)*, Common mongoose *(Herpestes edivadsii)* Ruddy mongoose *(Herpestes smithii)*, small Indian civet *(Viverricula indica)* etc. among herbivores chital *(Axis axis)*, Sambar *(Cervus unicolor)*, Nilgai *(Boselaphus tragocamelus)*, Chawsingha *(Tetracerus quadricornis)*, Chinkara *(Gazella gazella)*, Wild pig *(Sus scrofa)*, Common langur *(Presbytes entellus)*, Procupine *(Hystrix indica)*, Indian hare *(Lepus nigricollis ruficaudata)*.

1.5.7 Human settlements

The Gir protected area is under heavy anthropogenic influence from the 97 peripheral revenue villages within the buffer of six km from park boundary having human and livestock populations of approximately 1,50,000 and 95,000, respectively. In addition to that there are 54 pastoral settlements (locally called "*Ness*") of *Maldharis* having human population of 2,540 and cattle population of 9,811 and 14 forest settlement villages (permanent human habitation with cultivable lands –administered by forest department) having a population of 4,500 human and 4,200 livestock (Singh & Kamboj, 1996).

Figure- 1.2: Four broad habitat types in Gir Protected Area.



1.5.8 People

The *Maldharis*, the local pastoralists are residents in the sanctuary area of the PA. Maldhari is not a traditional tribe but a collective term for different pastoral communities i.e. Rabari, Charan, Bharwad, Ahir and Kathi. They live in semi temporary habitation, called *Ness.* A Ness is usually a cluster of huts situated near a perennial water source. The only source of livelihood of Maldhari is animal husbandry. They herd regionally famous milk breeds of cattle and buffalo, and sell milk and dairy products in nearby villages and towns. Living alongside nature for long period, they have developed deep rooted value system and a tolerant attitude. To coexist with nature and wildlife around them, being vegetarian is just an example.

1.6 Objectives

The overall objective of the study was to quantify the impact of sympatric livestock grazing on wild ungulates, mainly chital, and on vegetation. The basic information on chital ecology and behaviour would provide a basis for the better management practice to conserve and mange the large carnivore population especially lions; and to mitigate negative impact of livestock grazing, if any. The major objectives of this study were as follow:

- *To estimate the density, demographic structure and nutritional condition of chital, in areas sympatric with livestock and devoid of livestock*
- *To study the seasonal activity patterns of chital and livestock.*
- *To study the seasonal habitat use by chital and livestock.*
- *To estimate the seasonal food habits of chital and livestock.*
- *To evaluate the impact of livestock foraging on the vegetation quality, quantity and community structure.*

1.7 Study Hypothesis and Experimental Design

1.7.1 Study hypothesis

Hypothesis-1 ***Presence of sympatric livestock results into poor population performance of chital***

It is generally believed that the presence of sympatric livestock is detrimental to wild ungulate population and it subsequently affects the population demography i.e. population densities, group sizes and body condition. If competition were a major limiting factor for chital then in the areas sympatric with livestock chital should have: 1) low population density which is a medium to long term response, 2) Poor body condition - medium term response 3) Smaller group size which is an immediate response to interspecific competition, compared to the areas devoid of livestock.

Hypothesis-2 ***Presence of sympatric livestock results into competition with wild ungulates for habitat and food resources***

The essential criteria to determine interspecific competition is to measure the overlap in utilization of available habitat and food resources. If competition is likely to prevails then there should be 1) higher overlap in habitat utilization and preference pattern of chital and livestock 2) higher seasonal as well as overall dietary overlap between chital and livestock.

Hypothesis-3 ***Presence of sympatric livestock depletes or deteriorates habitat and food resources of chital***

The long term grazing by sympatric livestock can potentially generate negative trends in the structure and composition of plant communities. The altered vegetation composition and structure subsequently affects the availability of preferred food and habitat resource. If sympatric livestock grazing is detrimental then 1) In areas with sympatric livestock the biomass of chital food items is lower than areas devoid of sympatric livestock 2) an increasing trend in overall tree density, browse species density, sapling density and ground cover composition could be detected with increasing distance from *Maldhari Ness* sites.

1.7.2 Experimental Design

The present study has been designed to understand the ecology of chital and their ecological interface with sympatric livestock. Therefore a systematic effort was made to evaluate the direct as well as the indirect impact of sympatric livestock grazing on the ecology of chital population (Figure – 1.1).

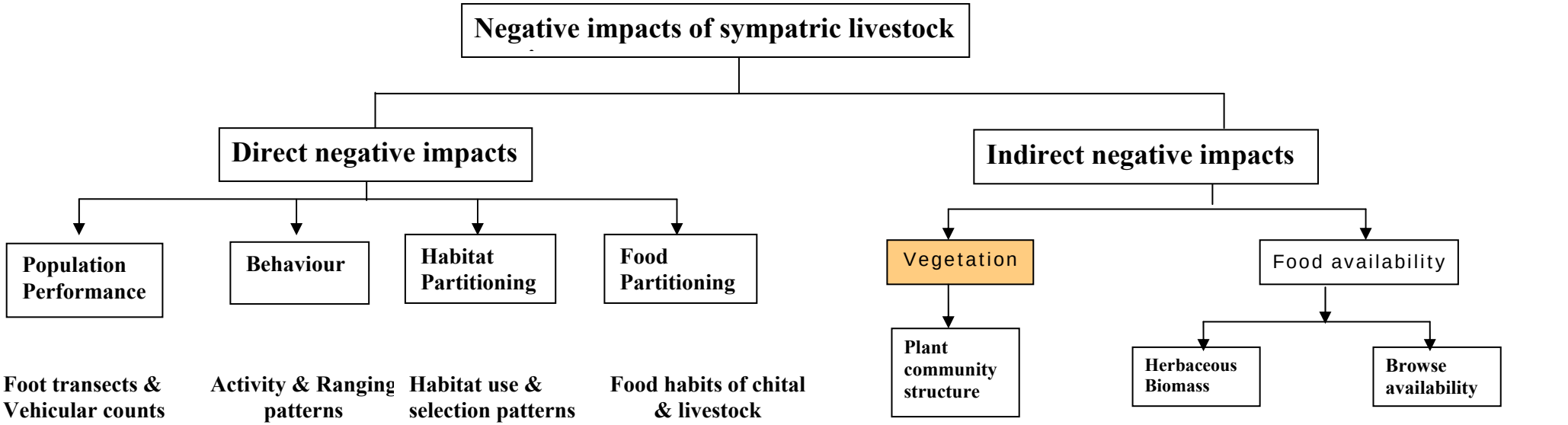
The intensive field data collection was carried out from February 2004 to May 2006. The study was designed to incorporate the consequences of sympatric livestock grazing on the ecology of chital in Gir. The ecological interactions between chital and sympatric livestock were studied at different ecological and spatial scales.

The population abundance & demography of chital and other wild ungulates were studied at a larger landscape scale i.e. Gir PA (1412 km^2). Subsequently to minimize the confounding effects of rainfall and associated differences in vegetation communities operating at the landscape scale, two adjacent areas, one with livestock and another without livestock in eastern Gir sanctuary were selected for an intensive study. The intensive study area in eastern Gir sanctuary had abundant wild ungulate population as well as high livestock population with relatively homogeneous environmental conditions. The spatial and temporal patterns of habitat utilization and selection, as well as broader activity patterns of chital and *Maldhari* livestock were studied in the intensive study area. The potential for competition between chital and sympatric livestock within each habitat (functional/ ecological scale) was studied by examining the seasonal food habits and seasonal diet niche breadth.

The long term as well as short term consequences of livestock grazing on forage availability as well as structure and composition of vegetation types was also assessed in the intensive study area. The impact of sympatric livestock on above ground biomass and those species contributing to chital diet was assessed using vegetation exclosures at different intensity of livestock grazing, while browse production within the reach of chital was assessed on paired lopped and unlopped *Anogeissus latifolia* trees in areas used by livestock. Impact of livestock grazing on plant community structure and composition was assessed on radiating transects. *Maldhari Ness*

locations are near perennial water sources. This location effect would likely confound the results of livestock grazing impact on vegetation near *Ness* sites. Experimental design for vegetation sampling took into account this location effect so as to minimize it's effect on inferences drawn from the study results.

Figure-1.3: Assessment of the consequences of sympatric livestock grazing on chital and their immediate ecosystem.



CHAPTER 2

Population Density and Demography of Wild Ungulates and Domestic Livestock

2.1 Introduction

Population size is the currency by which the success of wildlife management programs are ultimately judged (Lancea *et al*, 1996). In any forest ecosystem, ungulates, being primary consumers, play an important role in sustenance of higher trophic levels. A healthy wild ungulate population is crucial, apart from it's aesthetic, economic and nutritional contribution to the forest system, and wildlife wealth. It directly or indirectly affects forest structure, regeneration and consequently, other animal species (Crawley 1983, Kortland, 1984, Owen-Smith, 1987).

In many studies ungulate population density or prey biomass density estimations have been done (see review of literature). But a single estimate of population size at one point in space and time has limited values for conservation and management of wildlife populations. Such estimation provides little information for management strategies. Instead, temporally spaced population estimates in the same area for longer duration or at same time in different sites or habitats would help draw inferences about population trends and ecological processes (Droege, 1990).

The interest in the understanding of population trends of wild ungulate becomes very crucial if their resources are shared with sympatric livestock. Several studies (Prins 1992, 2000; Runyoro *et al* 1995; Mishra *et al* 2002; Mishra *et al* 2004) have reported competition between wild ungulates and livestock. In some instances wild ungulate community has showed an increase in their population after removal of sympatric livestock (Prins, 2000; Madhusudan, 2004). However, Rannestad *et al* (2006) reported a higher wild ungulate density in the pastoral areas compared to adjacent protected area devoid of livestock. In this chapter, a systematic attempt is made to understand the effect of livestock on wild ungulate demography especially chital density, group sizes and body condition.

Group size is generally considered as a fundamental attribute of the social organization of many ungulates (Jarman, 1974; Clutton-Brock & Harvey, 1978b; Shankar Raman, 1997). Ungulates commonly experience considerable seasonal, climatic and spatial variations in resource availability in arid and semi arid tropical environments (Illius & O'Connor, 2000). Hence

the population dynamics of wild ungulates are affected by the change in plant growth, phenology and habitat structure. Other than population density and group size, body condition is also an important parameter to evaluate the population status and health (Harder & Kirkpatrick, 1996). The body condition of ungulates is indicative of the nutritive carrying capacity, competition between wild and domestic ungulates, diseases prevalence and the potential of the population to increase (Sinclair & Norton-Griffiths, 1982; Brochu, 1988; Leader-Williams, 1991; Clutton-Brock *et al*, 1997).

Livestock grazing is believed to deplete available forage and important habitat attributes needed by wild ungulates by alteration of vegetation community structure and composition (Hayes & Hole, 1996; Vavra & Sheehy, 1996; Vavra *et al*. 1999).

If competition with livestock were a major limiting factor for wild ungulates then in areas of livestock use, wild ungulates should have lower densities, poor body condition and form smaller groups (Jarman, 1974; Putman, 1996; Prins & Olff, 1998; Petren & Case, 1998; Madhusudan, 2004). These hypotheses were tested by comparing data on the above parameters of wild ungulates, especially chital (*Axis axis*), the most abundant ungulates in areas with livestock and devoid of livestock in the Gir.

2.2 Methods

The population study was carried out at two spatial scales. At the landscape scale; the entire protected area of Gir (1412.12 km^2) was sampled for ungulate densities, body condition and group sizes of chital. At a local scale (intensive study site) to minimize the confounding effects of rainfall and associated differences in vegetation communities and productivity (Geist, 1974) two sites within Gir East were selected that had similar topography, rainfall and vegetation but differed only in the terms of livestock presence.

2.2.1 Wild ungulate density estimation

At the landscape scale, entire Gir PA was systematically sampled by line transect method using distance sampling for ungulate density estimation (Anderson *et al*, 1979; Burnham *et al*, 1980). For administrative purpose Gir protected area is divided into 37 forest blocks. To systematically sample the

entire park, a forest block was considered as an individual sampling unit and line transects measuring 2 to 3 km in length were laid in 36 blocks and walked at least twice during winter 2006. A total of 83 foot transects were sampled. The data on group size, sighting distance and sighting angle were recorded. The data collection was aided by a GPS unit (Garmin 12.0 & Magellan NAV 5000), LASER range finder (Bushnell) and magnetic compass (SUUNTO see through compass). Field data were analyzed using the computer software program 'DISTANCE 5.0' (Buckland *et al*. 1993; Laake *et al*. 1999, Thomas *et al*. 2002). The results were calculated for each ungulate species for the entire PA.

The results of density estimates were statistically compared using analysis of variance (ANOVA) in SPSS (Release 8.0.0, 1997) for three ecological and management zones namely western Gir sanctuary, eastern Gir sanctuary and National Park. Though there are no abrupt ecological change between two adjacent zones, vegetation types (Qureshi & Shah, 2004) and associated productivity differs among them reflected by the rainfall gradient decreasing from west to east. These zones differs in livestock grazing pressure from no grazing in Gir National Park, moderate grazing in western Gir sanctuary and to high grazing pressure in eastern Gir sanctuary (Khan *et al*, 1996). However, to understand the effect of sympatric livestock at landscape level, the densities of chital and other wild ungulates were statistically compared using independent sample *t* test for National Park area i.e. devoid of livestock and sanctuary area i.e. area where livestock is sympatric.

To examine the effect of rainfall on the wild ungulate population especially chital density, entire protected area was categorized into four precipitation zones (mean annual precipitation) i.e. high rainfall (896 mm), moderate rainfall (785 mm), low rainfall (697 mm) and poor rainfall (513 mm). Wild ungulate and chital densities were estimated for each of these rainfall zones by line transect samples drawn from each of these zones. Simple linear regression analysis (Zar, 1984) was used to establish the relationship between rainfall and wild ungulate density as well as chital density.

To control for the effect of varying rainfall and associated vegetation responses, two areas in Eastern Gir (At local scale) were intensively sampled

that had similar rainfall and vegetation community but differed in one area having livestock and livestock being absent in the other area. The wild ungulate and chital densities were estimated using randomly laid line transects of 2-3 km length. The exercise was repeated for all three seasons to understand the effect of seasonality on the resource distribution and subsequently on chital and other wild ungulate densities in areas devoid of livestock and in areas where livestock is sympatric.

2.2.1.1 The sampling strategy and sample size: accuracy and precision

Estimating ungulate densities is costly in terms of time and resources. A convenient method used by Park managers for estimating ungulate population has been through road counts (Singh & Kamboj, 1996). Since roads are not randomly placed and major habitat manipulations are done along the roads like fire lines and artificial water holes, density estimates obtained from vehicle transects are likely to be positively biased. We collected the road count data on wild ungulates during same season in these three ecological zones and compared the density estimates derived from systematic foot transect and road counts to evaluate the bias and precision of these methods.

Attaining the maximum precision in the population estimation of any wild animal is crucial for it's management. To arrive at the minimum sample size required for maximum precision, the density and pecent Coefficient of Variation (% CV) were computed for random subset of foot transect data with varying sample sizes with replacement. The analysis of random subsets was done with sample size increasing in multiples of 10 transect walks.

2.2.3 Ungulate population growth rate

Population estimation of ungulates has been done in the past by various studies in Gir (Joslin, 1973; Berwick, 1974; Khan, 1993; Goyal *et al*, 2004). Though the methods used and the sampling strategy they adopted differed somewhat between studies, e.g. systematic foot transect to random road counts, they do provide an indication of population size of wild ungulates in Gir since the declaration of Gir forests as a protected area. Besides, this is one of the few areas in India where long term scientific data exist on wild ungulate densities. the realized rate of increase (Caughley, 1977) of wild ungulate as a community as well as chital and sambar populations of Gir

protected area was computed to get a better understanding on how wild ungulates and chital react to a protection regime under conditions of natural predation and potential competition with livestock.

2.2.4 Group sizes of chital and other wild ungulates

Intensive surveys were conducted through out Gir forests for chital and other wild ungulate groups. Data on group size and composition of different wild ungulates were recorded. Each group was distinguished into easily identifiable age & sex categories (Schaller, 1967). The age categories were 1) fawn (< 6 months) 2) juvenile (< 1 year but > 6 months) 3) sub adult (< 2 years but > 1 year) 4) Adult (> 2 years). Age structure of chital and other wild ungulate populations was computed from the data pertaining to percentage contributions of each age-sex class to total population.

Mean (MGS) and typical group sizes (TGS) were computed for chital and other wild ungulates (Jarman, 1974). The fawn to doe ratio was calculated to understand the recruitment (Schaller, 1967; Caughley, 1977; Jhala, 1991). Along with that age and sex ratio was also computed to evaluate the population structure (Schaller, 1967).

2.2.5 Body condition of chital

The nutritional pinch period in Gir is just prior to monsoon. During this period (last week of May and first week of June) I sampled throughout Gir and scored a minimum of three chital in each group encountered for body condition. The index consists of scoring different regions of an ungulate body, i.e. rump, thigh, pelvic girdle, pectoral girdle and ribs, on a score of 1 to 5, 1 being extremely poor while 5 being excellent condition (Riney, 1960).

The scores on various body parts were likely to be correlated amongst themselves. Hence, to reduce the dimensionality and redundancy of the data, a principal component analysis (PCA) was conducted (McGarigal *et al*. 2000). Principal component scores of chital body condition were statistically compared between areas devoid of livestock and areas in which chital were sympatric with livestock.

2.2.6 Population Monitoring of domestic livestock within the intensive study site

A total of six *Maldhari* settlements, locally known as '*Ness',* were located in the intensive study area**.** These nesses were seasonally monitored

throughout the study period as some of the *Maldharis* migrate out from the PA after monsoon to adjacent revenue villages and come back before the onset of next monsoon. A total head count of the livestock of each of these *Ness* was carried out, mostly during evening when all livestock used to come back to their ness sites. Data on demographic structures of the livestock belonging to each *Maldhari* family was recorded. All the cattle and buffalos were classified A) milk yielding B) adult but not milk yielding C) non-productive D) sub adult female E) adult male F) sub adult male G) calf. The livestock holding of each *Ness* site and average livestock holding of each *Maldhari* family was calculated for different seasons.

All *Maldhari Ness* sites within the intensive study area were monitored from June 2004 to May 2006 to collect data on seasonal population estimation and demography. Livestock of different *Ness* sites was followed from early morning to late evening with a hand held GPS unit to plot their movement pattern and maximum distance traveled from the respective *Ness* site was computed. Density of the livestock was calculated on the basis of average foraging area calculated after generating a buffer consisting of the foraging radius around each study ness.

2.3 Results

2.3.1 Ungulate density estimation: *Gir Landscape*

A total of 82 transects (Figure – 2.1) with an effort of 231 km were walked during the winter of 2006 and a total of 207 sightings of wild ungulates were obtained. Wild ungulate density ($\hat{D}$ ± se) was highest in western sanctuary (60.1 ± 12.2 km^{-2}) compared to eastern sanctuary (38.8 ± 9.1 km^{-2}) and National Park (51.8 ± 10.9 km^{-2}). Among wild ungulates chital was the most abundant (44.8 ± 7.1 km^{2}) species followed by sambar (2.9 ± 0.8 km^{-2}), nilgai (1.2 ± 0.5 km^{-2}), wild pig (0.8 ± 0.3 km^{-2}) and four horned antelope (0.3 ± 0.1 km^{-2}).

Chital density ($\hat{D}$ ± se) was highest in western sanctuary (55.3 ± 12.5 km^{-2}) compared to National Park (40.5 ± 9.6 km^{-2}) and eastern part of the

sanctuary (35.1 ± 9.9 km^{-2}). The density of the second most abundant species sambar was found to be high in National Park area followed by western part of the sanctuary. Sambar was seen on very few occasions in eastern sanctuary and hence its density could not be computed for this area (Table – 2.1). Nilgai density was relatively higher in eastern sanctuary compared to western sanctuary (Table - 2.1). Whereas wild pig density was high in western sanctuary compared to eastern sanctuary, however due to very few sightings of wild pig and nilgai in the National Park, their densities could not be computed. Chinkara and the four horned antelope was the least abundant species among wild ungulates in Gir and patchily distributed in the Park. The density of four horned antelope could be computed only for western sanctuary as there were very few sightings in the other two zones. Chinkara distribution was largely restricted to open grassy patches of eastern Gir sanctuary and the periphery of the protected area; hence, with very few sightings of chinkara, their density could not be computed (Table – 2.1). Wild ungulate densities across the park showed a gradient decreasing eastward (Figure- 2.1). Chital density was significantly different between these three zones (One way ANOVA, $F = 12.34$, $p \leq 0.001$). However, chital density in the eastern Gir sanctuary (livestock presence) did not differ significantly from the National Park (livestock absent) (*Tukey's Posthoc* test, $p= 0.632$) and the western sanctuary had significantly higher chital density than the National Park (*Tukey's Posthoc* test, $p\leq 0.001$). To evaluate the effect of livestock presence at landscape level the density data were pooled for sanctuary area and National Park and compared statistically. The independent sample *t*- test revealed no effect of livestock grazing on either wild ungulate or chital density (Independent sample *t* test, $t = 1.242$, $p = 0.22$). The result of simple linear regression indicated that the density trends correspond to the rainfall gradient which subsequently depicts the habitat productivity in different rainfall zones ($R^2 = 0.851$, $p= 0.077$, $n= 4$) (Figure- 2.2).

Figure- 2.1: Location of foot transects on a precipitation gradient map of Gir Protected Area. Map inset shows the location of Gir within the State of Gujarat, India.

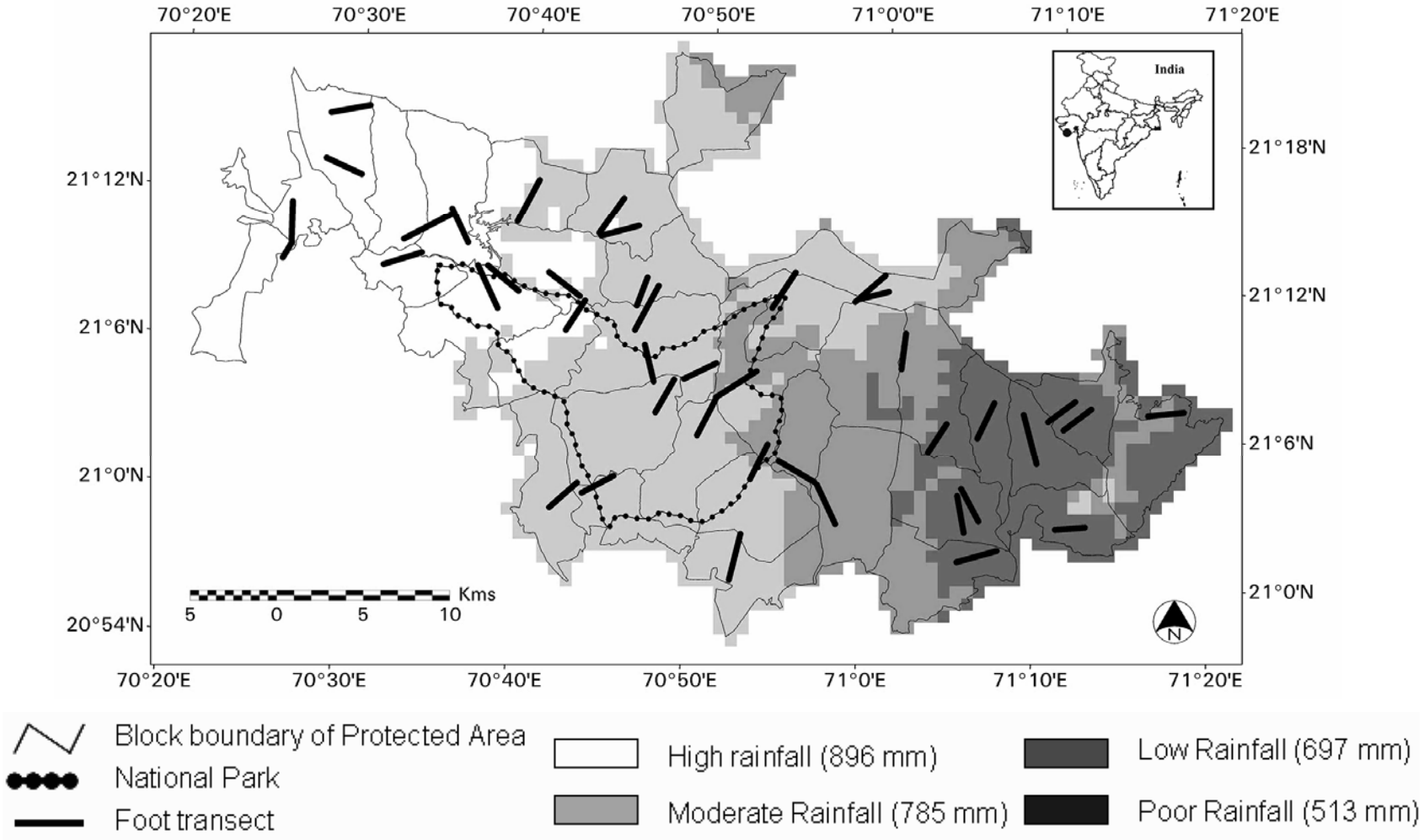
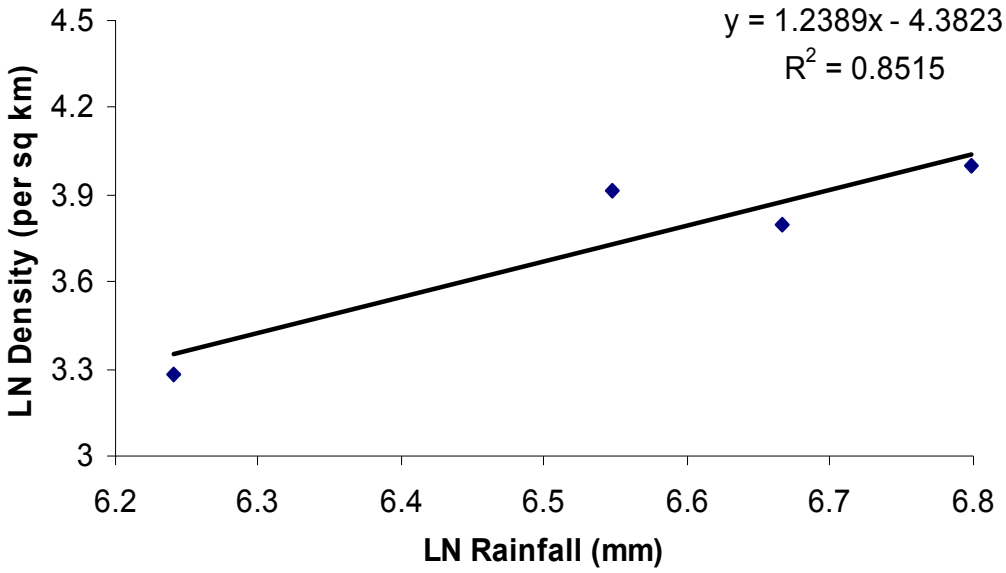


Table- 2.1 Wild ungulate densities ($\hat{D}$ ±SE) in Gir forests as estimated by systematic foot transect during winter of 2006.

	Gir Protected Area		EAST		CENTRAL		WEST		Livestock Present		Livestock Absent	
	Density (±SE)	Group Density (±SE)	Density (±SE)	Group Density (±SE)	Density (±SE)	Group Density (±SE)	Density (±SE)	Group Density (±SE)	Density (±SE)	Group Density (±SE)	Density (±SE)	Group Density (±SE)
Wild Ungulates	**48.25** (6.1)	**10.67** (1.1)	**35.77** (9.1)	**6.30** (1.3)	**51.76** (10.9)	**12.34** (2.1)	**60.06** (12.2)	**14.07** (2.6)	**48.7** (7.7)	**9.50** (1.2)	**52.89** (10.8)	**12.50** (2.0)
Chital	**44.77** (7.1)	**8.00** (1.1)	**35.08** (9.9)	**5.78** (1.4)	**40.53** (9.6)	**7.18** (1.4)	**55.25** (12.5)	**10.91** (2.2)	**47.04** (9.3)	**7.60** (1.3)	**46.52** (23.9)	**7.38** (1.4)
Sambar	**2.86** (0.8)	**1.80** (0.5)	*	*	**6.85** (2.0)	**4.01** (1.1)	**2.00** (1.5)	**1.11** (0.7)	**1.19** (0.8)	**0.65** (0.4)	**6.4** (1.8)	**3.83** (0.9)
Nilgai	**1.16** (0.5)	**0.47** (0.2)	**1.17** (0.6)	**0.55** (0.3)	*	*	**0.58** (0.4)	**0.85** (0.5)	*	*	*	*
Four-horned-antelope	**0.27** (0.1)	**0.18** (0.1)	*	*	*	*	**1.10** (0.8)	**0.83** (0.6)	*	*	*	*
Wild pig	**0.77** (0.3)	**0.27** (0.1)	**0.40** (0.3)	**0.24** (0.2)	*	*	**2.79** (1.3)	**0.78** (0.3)	*	*	*	*

Figure- 2.2: Relationship between chital density and rainfall of four rainfall zones of Gir.



2.3.2 Group sizes of chital and other wild ungulates: *Gir Landscape*

2.3.2.1 Winter

Among all wild ungulates, chital forms largest group (MGS of 7.1 ± 0.8 and TGS of 18.5). The nilgai were largely confined to eastern Gir sanctuary and sambar largely confined to National Park (central) form smaller groups in Gir (2.5 ± 0.6 MGS and 4.1 TGS for nilgai; 1.7 ± 0.2 MGS and 2.4 TGS for sambar). The mean and typical wild pig group size was 3.0 (± 0.6) and 3.7, respectively. The larger group size was observed for wild pig in western sanctuary (4.3 ± 0.3 MGS and 4.4 TGS) than eastern sanctuary area (1.7 ± 0.3 MGS and 1.8 TGS). The four horned antelope was mostly observed in pair, with a mean group size of 1.5 ± 0.2 and typical group size of 1.7 (Table-2.2).

Table- 2.2: Typical (TGS) and Mean Group sizes (MGS ± SE) of different ungulate species during winter 06 in Gir Protected Area.

	GIR		EAST		CENTRAL		WEST	
	MGS (±SE)	TGS	MGS (±SE)	TGS	MGS (±SE)	TGS	MGS (±SE)	TGS
Chital (n = 1002)	**7.11** (0.8)	18.52	**8.74** (1.8)	25.68	**5.64** (0.75)	10.00	**6.81** (1.15)	15.70
Nilgai (n=27)	**2.45** (0.64)	4.11	**2.14** (0.5)	2.73	**5.00** (3.00)	6.80	**1.00**	1.00
Sambar (n= 42)	**1.68** (0.23)	2.43	**2.00**	2.00	**1.52** (0.19)	2.09	**5.00**	5.00
Four horned antelope (n= 9)	**1.50** (0.22)	1.67	**2.00**	2.00	**3.00** (0.71)	1.67	**1.33** (0.33)	1.50
Wild pig (n= 18)	**3.00** (0.63)	3.67	--	--	--	--	**4.33** (0.33)	4.38
Chinkara (n=3)	**2.00**	2.00	**2.00**	2.00	--	--	--	--

2.3.2.2 Summer

Similarly, during summer also, chital formed largest group among all wild ungulates (MGS of 6.4 ± 0.5, and TGS of 11.2). However, chital group sizes were smaller than winter (Table-2.3). There was no major change observed in the mean and typical group sizes of sambar and nilgai (2.5 ± 0.6 MGS and 3.9 TGS for sambar and 2.5 ± 0.6 MGS and 3.3 TGS for nilgai).

Wild pigs were observed only in the western sanctuary. The mean and typical group sizes were 4.0 (± 2.0) and 3.8, respectively. Chinkara was sighted once as a pair in the eastern sanctuary, whereas chowshinga was not sighted during summer sampling (Table-2.3).

Table- 2.3: Typical (TGS) and Mean Group sizes (MGS ± SE) of different ungulate species during summer 05 in Gir Protected Area.

	GIR		EAST		CENTRAL		WEST	
	MGS (±SE)	TGS	MGS (±SE)	TGS	MGS (±SE)	TGS	MGS (±SE)	TGS
Chital (n= 783)	**6.42** (0.5)	11.16	**4.93** (0.5)	6.63	**5.97** (0.9)	10.60	**8.02** (1.1)	13.83
Nilgai (n= 15)	**2.5** (0.6)	3.27	**2**	3.00	**2**	2.50	**3.00** (1.2)	3.89
Sambar (n= 25)	**2.5** (0.6)	3.96	**3**	2.00	**1**	1.00	**3.17** (0.9)	4.58
Wild pig (n =4)	**4.00**	4.00	**--**	--	--	--	**4**	4.00
Chinkara (n=2)	**3.00**	2.00	**2**	2.00	--	--	--	--

2.3.3 Age structure of different wild ungulates in Gir

The average herd compositions (age–sex structure) of different wild ungulates are given in Table-2.4. Except chital, the juvenile stage could not be classified as a separate age group. Fawns contributed more than 5 % to the group composition of chital, sambar and wild pig. The adult sex ratio male: female for chital was 1: 1.79; the ratio of fawns to adult female was 1: 2.43. Similarly the adult sex ratio male: female for sambar was 1:1.46 and fawn to adult female ratio was 1: 2.56 adult females. Whereas in nilgai adult sex ratio was 1:1.09 and fawn to adult female ratio was 1: 5.29.

Table- 2.4: Age structure of wild ungulates in Gir Protected Area.

Species (n)	Adults		Sub adults		Juveniles		Fawns % (SE)	Un identified % (SE)
	Male % (SE)	Female % (SE)	Male % (SE)	Female % (SE)	Male % (SE)	Female % (SE)		
Chital (n=1334)	**22.92** (0.8)	**39.71** (0.8)	**5.09** (0.3)	**10.48** (0.41)	**2.87** (0.23)	**5.27** (0.32)	**8.23** (0.4)	**5.43** (0.5)
Sambar (n=389)	**29.41** (2.2)	**42.91** (1.8)	**4.77** (0.8)	**3.90** (0.7)	**0.51** (0.2)	**1.46** (0.4)	**14.77** (1.1)	**2.27** (0.7)
Nilgai (n=99)	**39.53** (4.4)	**41.98** (3.6)	**6.77** (1.9)	**3.05** (1.1)	**2.56** (1.0)	**2.67** (1.1)	**2.71** (0.9)	**0.77** (0.6)
Four horned antelope (n=32)	**21.57** (4.6)	**32.83** (6.5)	--	--	--	--	**5.05** (2.7)	**40.56** (8.2)
Wild pig (n=31)	**23.28** (5.9)	**24.57** (5.2)	**6.77** (4.5)	**3.12** (1.7)	--	--	**10.81** (3.7)	**31.45** (7.6)
Chinkara (n=21)	**25.00** (9.2)	**37.50** (8.1)	--	--	--	**12.50** (3.3)	--	**25.0** (10.1)

2.3.4 Body condition of chital: *Gir Landscape*

The principal component analysis (PCA) extracted a single principal component that explained 68.25 % of the variation observed in the five body condition indices i.e. five different body regions. All condition scores contributed almost equally to this principal component, each with a factor loading of over 0.8 (Table-2.5).

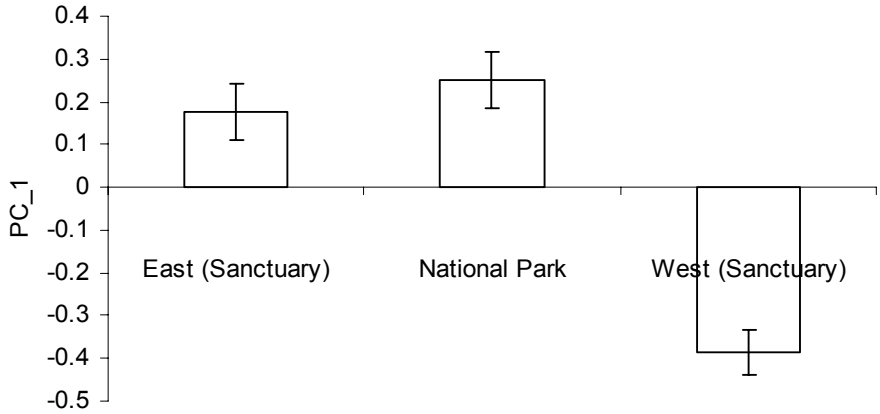
The PCA factor-1 was compared for eastern Gir sanctuary, western Gir sanctuary and National Park to evaluate the body condition of chital in these three ecological zones. Body condition differed between the three ecological zones of Gir (One way ANOVA, $F=32.4$, $p \leq 0.001$). In western Gir sanctuary

which had maximum rainfall and presence of livestock, chital had the poorest body condition in comparison to Central Gir (No livestock) and eastern Gir sanctuary (with livestock and lowest rainfall) (*Tukey's Posthoc test* p ≤ 0.001, Figure-2.3).

Table- 2.5: Principal component loading by different body condition indices on PC-1
(Component Matrix Extraction Method: Principal Component Analysis)

INDEX	Component - 1 Loading
Rump	0.844
Thigh	0.831
Pelvic	0.802
Pectoral	0.823
Ribs	0.830

Figure- 2.3: Body condition of Chital (scores of the first principal component) across the Gir Protected Area (Error bars are standard errors).



2.3.5 Chital density estimation: *Intensive Study Site*

The seasonal chital density trend in two ecologically similar sites differing in terms of livestock presence revealed that devoid of livestock area had higher densities in all seasons, although only summer density estimates were significantly different for these two sites (Independent sample *t* test, *t* = 2.75 p ≤ 0.05) (Table-2.6). During monsoon chital density was observed to be very high (66.2 ± 22.2 in the area with sympatric livestock; 116 ± 31.3 in devoid of livestock area).

Table- 2.6: Seasonal comparison of densities, typical group size and body condition of chital for areas with sympatric and devoid of livestock within the intensive study area.

	Grazed Area				Ungrazed Area			
	Density (SE)	**TGS**	**MGS (SE)**	**Body condition Mean PCA Score (SE)**	**Density (SE)**	**TGS**	**MGS (SE)**	**Body condition Mean PCA Score (SE)**
Summer	**50.32** (7.9) *(n=36)*	**8.76** *(n=87)*	**5.45** (0.5) *(n=87)*	**0.003** (0.08) *(n=160)*	**94.35** (14.5) *(n=32)*	**11.41** *(n=116)*	**5.57** (0.5) *(n=116)*	**0.004** (0.08) *(n=124)*
Winter	**57.82** (11.6) *(n=26)*	**12.46** *(n=53)*	**5.92** (0.9) *(n=53)*		**70.9** (17.7) *(n=16)*	**10.89** *(n=44)*	**5.95** (0.8) *(n=44)*	
Monsoon	**66.2** (22.2) *(n=14)*	**15.88** *(n=30)*	**9.55** (1.8) *(n=30)*		**116** (31.3) *(n=15)*	**29.91** *(n=35)*	**14.17** (2.8) *(n=35)*	

2.3.6 Typical and mean group sizes of chital: *Intensive study Site*

The average group sizes of chital herds were larger in the devoid of livestock area however, the average group size was not significantly different between areas with and without livestock (Independent sample *t* test; *t*= 0.31, p= 0.75, Table-2.6). Typical group sizes were also found increasing with respect to densities in both the sites. The TGS were observed larger in devoid of livestock area during summer and monsoon, but smaller during winter compared to areas with livestock presence.

2.3.7 Body condition of chital: *Intensive study site*

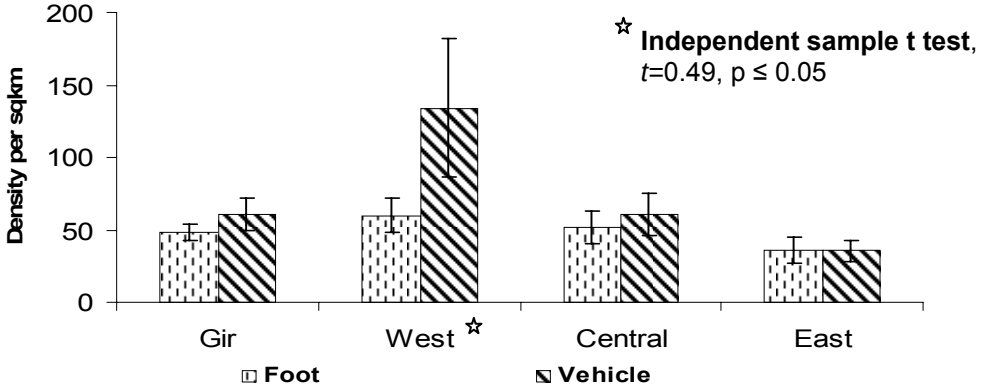
The principal component analysis (PCA) extracted a single principal component which explained 70.12 % of the variation observed in the five body condition indices i.e. rump, pelvic, pectoral, ribs and thigh. It had a maximum factor loading from pectoral girdle (71.9 %) but remaining indices too contributed almost equally to this principal component (Table-2.6). There was no significant difference in body condition of chital between areas with livestock and without livestock (Independent sample *t* Test, *t* = 0.64; p = 0.95) (Table-2.6).

2.3.8 Sampling strategy and sample size: *accuracy and precision*

2.3.8.1 Road count compared to systematic foot transect density estimates

The road count method was found to be overestimating the wild ungulate density for entire Gir protected area (vehicle transect: 60.5 ± 10.91; foot transect: 48.3 ± 6.1) as well as different managerial zones i.e. sanctuary west (vehicle transect: 134.3 ± 47.8; foot transect: 60.1 ± 12.2) and National Park (vehicle transect: 60.7 ± 14.5; foot transect: 51.8 ± 10.9). However, in case of eastern sanctuary, density estimates were quite similar (vehicle transects: 35.5 ± 6.9; foot transect: 35.8 ± 9.1). Although, vehicle transect method over estimated the density in all cases, statistically significant difference was observed only for western part of the sanctuary (Independent sample *t* test, $t = 0.49$ $p \leq 0.05$) (Figure- 2.4).

Figure- 2.4: Comparison of density estimates from foot transects and vehicle transects for Gir PA (Error bars are standard errors).

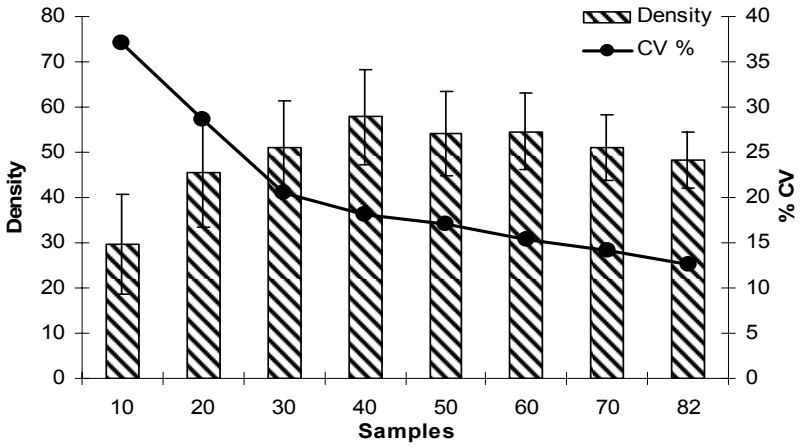


2.3.8.2 Effect of sample size on the precision and accuracy in ungulate density estimates

The analysis of random subsets of sample size increasing in multiples of 10, showed that an increase in the number of samples i.e. line-transect walks improves precision in density estimation (37.1 % CV with 10 samples decreases to 12.6 % CV with 82 samples). However, precision of density estimation does not change much after considering 40 samples in the analysis. The results also revealed that small number of samples

underestimates the density (29.8 ± 11.1 with 10 samples; 57.9 ± 10.5 with 40 samples) (Figure-2.5).

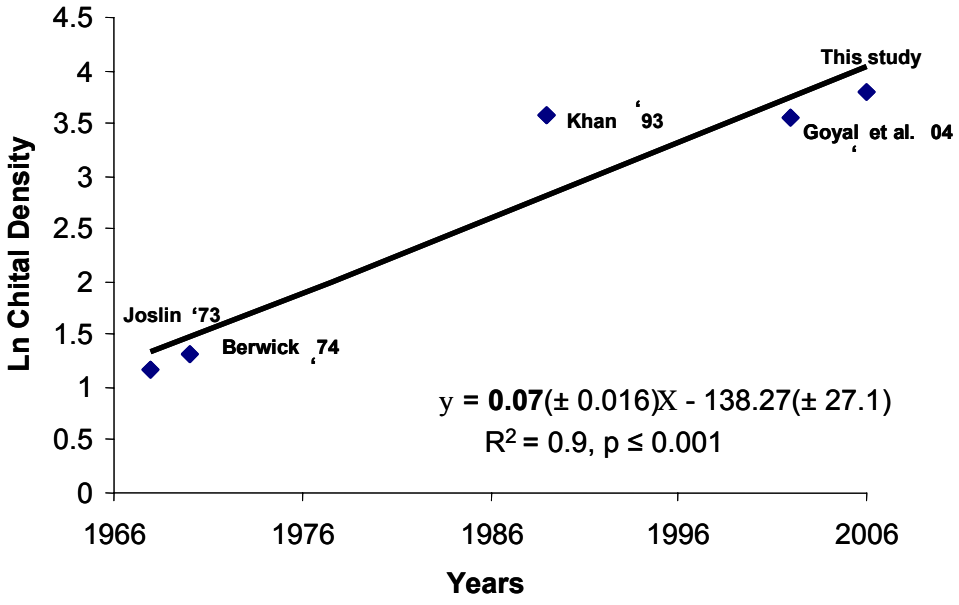
Figure- 2.5: Sampling adequacy of foot transects in Gir for estimating wild ungulate density (per square km). Error bars are standard errors.



2.3.8.3 Ungulate population growth rate for Gir PA

The realized rate of increased (*r* ± SE) for chital was 0.071 ± 0.014 (p≤ 0.001, R^2 = 0.90, n= 5) in Gir Protected Area, with initial population of 3.2 chital per km^2 (Joslin, 1973) to 44.8 chital per km^2 in the present study (Fig 2.6). For sambar, realized rate of increase were 0.0705 ± 0.006 (p≤ 0.05, R^2 = 0.88, n= 5).Wild ungulate community as a whole also had a realized growth rate (*r*) of 0.07 ± 0.016 (p ≤ 0.05; R^2= 0.85, n= 5).

Figure- 2.6: The realized rate of population growth of chital in Gir Protected Area between 1969 & 2006.



2.3.9 Population demography and density of domestic livestock

The maximum foraging area of livestock herds of eight forest settlements (six *Maldhari* sites, one forest settlement village (Timberwa) and one shrine (Tulsishyam temple)) was 95.2 Km^2 during monsoon followed by 76.3 km^2 during summer while minimum foraging area of livestock was observed during winter (65.9 km^2). Number of livestock herds in the intensive study area ranged from 61 in winter to 129 in monsoon. The livestock density in the area was highest during winter (31.4 livestock per km^2) followed by monsoon (30.1 livestock per km^2) while, livestock density was least during summer (24.7 livestock per km^2). Among all *Maldhari Ness* locations in the intensive study site, Ghudjinjwa was the biggest settlement with highest number of livestock and Leria was the smallest with relatively small livestock population (Table-2.7, 2.8 & 2.9).

Maldhari livestock is mainly composed of cattle and buffalo. Along with cattle and buffalo, *Maldhari* keep camel to carry fodder. Buffalo population was always higher than cattle population in all *Maldhari Ness*. Overall population structure of cattle and buffalo is largely composed of adult females followed by sub adult females accompanied by few adult males of cattle and buffalo for breeding purpose.

More or less, all *Maldhari Ness* show seasonal population fluctuation; as maximum livestock number was observed during monsoon (Table- 2.9) while during winter (Table- 2.7) and summer (Table- 2.8) livestock number decreased due to their seasonal migration to peripheral revenue villages. Maximum fluctuation in the average seasonal livestock population was observed for Asundrali from 394 livestock during summer to 699 during monsoon and minimum fluctuation was observed for Ghudjinjwa from 516 during summer to 599 during monsoon.

The livestock holding of average *Maldhari* family is shown in the Figure- 2.7. An average (±SE) *Maldhari* family keeps a livestock herd of 30.7 (± 1.5) in summer to 34.6 (± 1.3) in monsoon in the intensive study area. However, milk yielding animals are not more than 10 in any season. The adult population remains almost constant through out the year.

Table- 2.7: Average winter population and age structure of *Maldhari* livestock of different *Ness* sites of the intensive study site in East Gir.

Ness	Buffalo					Cattle					Camel	Total Livestock
	Adult Female	Subadult Female	Calf	Adult Male	Total	Adult Female	Subadult Female	Calf	Adult Male	Total		
Asundrali	164.50	77.00	58.00	6.50	306.00	46.50	24.00	36.50	4.00	111.00	2.50	419.50
Dodhi	108.50	42.50	45.00	13.50	209.50	43.50	20.00	33.50	3.50	100.50	0.50	310.50
Ghudjinjwa	271.00	127.00	63.50	12.50	474.00	28.50	20.50	14.50	2.50	66.00	10.00	550.00
Khajuri	129.00	78.00	37.00	12.00	256.00	22.00	6.50	10.50	3.00	42.00	1.00	299.00
Leriya	45.50	18.50	8.50	2.50	75.00	8.00	5.50	5.00	1.00	19.50	0.00	94.50
Mindha	103.50	47.50	20.50	9.50	181.00	34.00	14.50	6.50	2.50	57.50	0.00	238.50
Tulsishyam	6.00	0.00	2.00	0.00	8.00	42.00	2.00	1.0	1.00	46.00	0.00	54.00
Timberwa	43.00	11.00	10.00	3.00	67.00	19.00	9.00	5.00	1.00	34.00	0.00	101.00

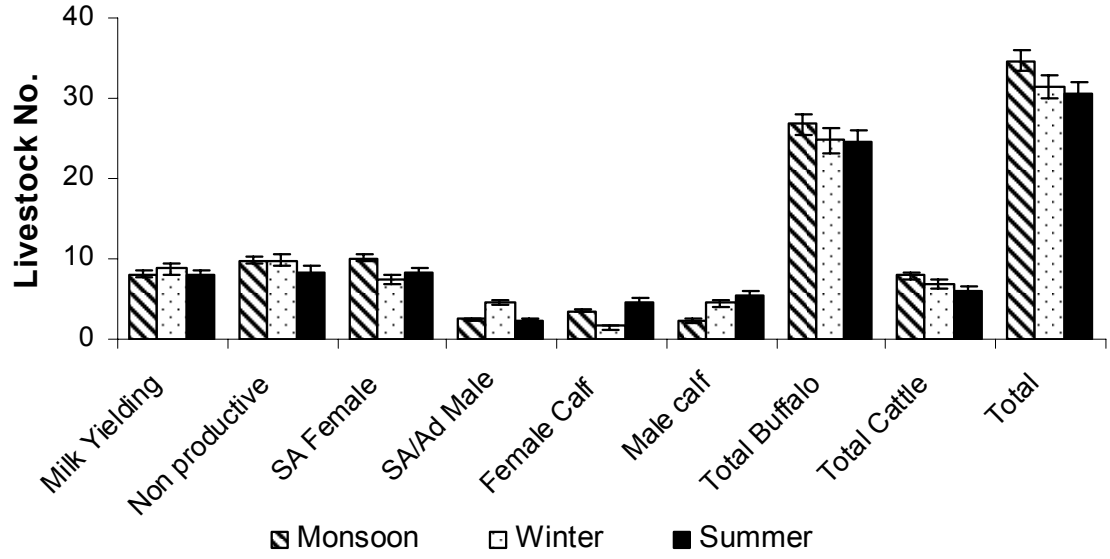
Table- 2.8: Average summer population and age structure of *Maldhari* livestock of different *Ness* sites of the intensive study site in East Gir.

Ness	Buffalo					Cattle					Camel	Total Livestock
	Adult Female	Subadult Female	Calf	Adult Male	Total	Adult Female	Subadult Female	Calf	Adult Male	Total		
Asundrali	165.50	77.00	77.50	7.00	291.50	48.50	25.00	40.50	4.00	100.00	2.00	393.50
Dodhi	98.00	39.50	47.00	11.50	174.50	37.50	18.50	29.00	4.00	76.00	0.50	251.00
Ghudjinjwa	253.50	121.50	96.50	18.50	445.50	28.50	20.50	13.50	2.50	59.50	10.50	515.50
Khajuri	120.00	71.50	42.50	13.50	225.00	20.00	6.50	15.00	2.00	35.00	0.00	260.00
Leriya	45.50	18.50	9.00	3.00	72.50	9.50	5.50	7.50	1.00	19.50	0.00	92.00
Mindha	104.00	47.50	28.50	8.50	176.50	34.50	14.50	12.50	2.50	57.00	0.00	233.50
Tulsishyam	4.00	1.00	0.00	0.00	5.00	40.00	2.00	0.00	1.00	43.00	0.00	48.00
Timberwa	42.00	14.00	5.00	3.00	64.00	19.00	7.00	2.00	1.00	29.00	0.00	93.00

Table- 2.9: Average monsoon population and agestructure of *Maldhari* livestock of different *Ness* sites of the intensive study site in East Gir.

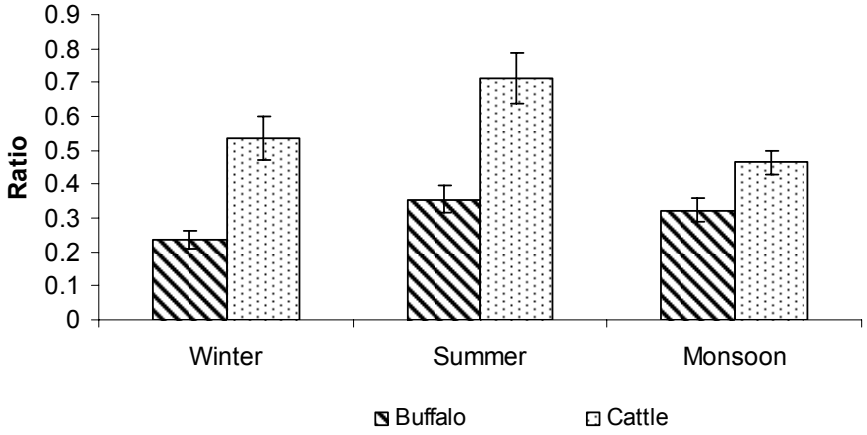
	Buffalo					Cattle						
Ness	Adult Female	Subadult Female	Calf	Adult Male	Total	Adult Female	Subadult Female	Calf	Adult Male	Total	Camel	Total Livestock
Asundrali	256.67	179.33	83.50	21.67	553.00	85.00	54.33	45.00	12.67	206.50	3.67	699.00
Dodhi	232.00	126.67	88.00	23.00	440.50	91.67	43.33	42.50	8.00	179.00	1.67	613.33
Ghudjijwa	267.00	153.00	72.00	21.50	513.50	44.50	19.00	15.50	3.00	72.50	13.00	599.00
Khajuri	146.00	72.00	50.00	8.00	276.00	20.00	10.00	12.00	1.00	43.00	0.00	319.00
Leria	68.00	31.67	12.50	3.33	107.00	22.33	10.33	7.00	1.33	37.50	0.00	150.00
Mindha	124.50	65.50	47.00	3.00	241.50	42.00	23.50	19.00	0.50	85.00	0.00	326.50
Tulsishyam	6.00	0.00	3.00	0.00	9.00	40.00	2.00	3.00	1.00	46.00	0.00	55.00
Timberwa	43.00	11.00	11.00	3.00	68.00	19.00	9.00	5.00	1.00	34.00	0.00	102.00

Figure- 2.7: Average seasonal livestock holding of a typical Maldhari family within intensive study site in east Gir. Error bars are standard errors.



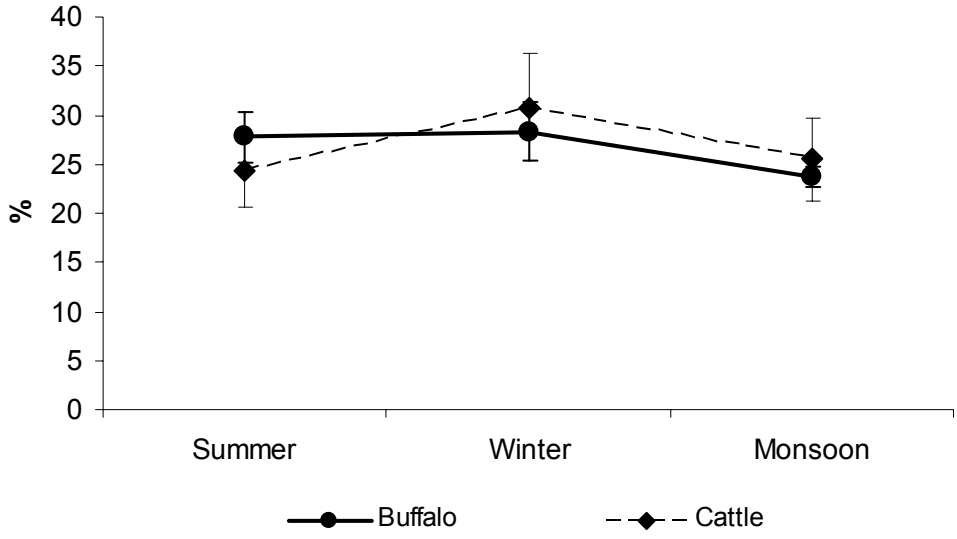
The population fluctuation is largely caused by high rate of juvenile mortality. Buffalo numbers were almost double than the cattle number in total livestock population. Calving period in cattle and buffalo was monsoon as maximum number of calves observed during this period. The calf to adult female ratio was poor in buffalos compared to cattle. The ratio of calf to adult female for buffalo ranged from 2.81 to 4.25 calves per adult females during summer and winter respectively. Whereas calf to adult female ratio for cattle ranged from 1.4 to 2.16 calves per adult female during summer and winter respectively (Figure-2.8).

Figure- 2.8: Average seasonal *cow:calf* ratio of cattle and buffalo in intensive study site in east Gir. Error bars are standard errors.



The average milk yielding population was not more than 30 % in either cattle or buffalo in any season. Highest milk yielding buffalos were recorded during summer and highest milk yielding cattle recorded during winter (Figure–2.9).

Figure- 2.9: Percent population of milk yielding buffalos and cattle in intensive study site during different seasons. Error bars are standard errors.



2.4 Discussion

2.4.1 Ungulate population densities, group sizes and chital body condition scores

Wild ungulate density at a site is a collective response of the population to several environmental factors, like nutrition, disease, competition and predation forces acting on it for the past several years (Caughley, 1977). Current ungulate density at a site can therefore be considered as a mid to long term cumulative effect of these factors on a population. Ungulate densities in Gir were determined primarily by the productivity of the habitats as they were correlated with rainfall. Depression of density by competition with livestock, if at all present, was masked by this overriding productivity effect of the vegetation communities. Total wild ungulate density almost doubled from east sanctuary to west sanctuary, chital densities too increased by a factor of 0.6 from east to west.

Among all ungulate species chital is common and widely distributed throughout Gir PA, and contributes 92.7 % of the total wild ungulate density. Sambar was the second most abundant species in Gir after chital (2.86 ± 0.81). Species that prefer moister vegetation communities like sambar were found in higher densities in the western and central parts of Gir, while arid adapted species like chinkara occurred more in the eastern part of the sanctuary. The sambar density has increased steadily over last three decades (Berwick, 1974; Khan *et al* 1996; Goyal *et al* 2004). The nilgai population was mostly restricted to eastern sanctuary and sanctuary border as also observed by Khan (1993), due to it's preference for open and undulating areas (Berwick, 1974). The nilgai density was relatively low but has increased from 0.37 per km^{-2} in 1990 (Khan, 1997) to 1.16 ± 0.47 km^{-2} (this study). The wild pig population has been keeping low (0.17 km^{-2}) since 1970's (Berwick, 1974). Berwick (1974) reported a catastrophic decline probably due to hog cholera in wild pig population which was second most abundant ungulate after chital till 1967 (Wynter-Blyth, 1949; Yuvraj, 1959). A later study by Khan (1993) also reported very low wild pig density (0.91 per km^2). The present study also reports very low wild pig density (Table-2.1). A new threat of hybridization with

feral domestic pigs now threatens this wild pig population as several peripheral village administrations have recently started keeping pigs to clean up domestic waste. The four horned antelope seems to occur inherently at low density due to their restricted distribution on grassy slopes of deciduous forests. The density of four horned antelope has remained low since 1970's.

Though total wild ungulate density was higher in areas devoid of livestock this difference was not statistically significant. Chital densities did not differ between areas with and without livestock. The National Park area where livestock were absent consisted of typical sambar habitat while eastern Gir sanctuary with sympatric livestock was poor sambar habitat. Sambar densities being higher in areas devoid of livestock was an artifact of these areas being good sambar habitat (Table-2.1).

Ungulate biomass is correlated with plant productivity, evidences are both from the arctic (Skogland, 1980), and from East African tropical grazing ecosystems (Coe *et al*. 1976, Thackeray, 1980). Rainfall is a good index of habitat productivity (Harrington, 1995; Hobbs, 1991, Allcock & Hik, 2003).The wild ungulate and chital density estimates increase from east to west with increasing rainfall gradient conforming to the expected pattern dictated by habitat productivity (Fig-2.1).

Food resources are major a limiting factor and at times regulate ungulate populations (Bobek, 1977; Sinclair, 1977; Bayliss, 1985; Sinclair *et al*, 1985; Skogland, 1985 & 1990, Fryxell, 1987; Dublin *et al*, 1990). On the Serengeti plains in East Africa, the migratory wildebeest (*Connochaetes taurinus*) are considered to be regulated by density-dependent food limitation in the dry season (Sinclair, 1979, 1985; Sinclair & Norton-Griffiths, 1982; Sinclair *et al*. 1985). Due to this overriding effect of habitat productivity on ungulate density, any negative impact of sympatric livestock on wild ungulate community would be masked. When this masking effect of rainfall was controlled by selecting two sites with similar rainfall and vegetation communities, differing only in presence of sympatric livestock, little evidence was found in support of the competition hypothesis (Table-2.6). However, density of chital in the area devoid of livestock was higher even though it was statistically insignificant during monsoon and winter. It is likely that during years of extreme stress such as droughts, food resources may become

extremely limiting factor resulting in competition between livestock and chital. It is also probable that since the study period covered reasonably good rainfall years, the short term response of group sizes and body condition of chital did not show any response to sympatric livestock, while chital density which is a long term population response was marginally higher in areas devoid of livestock. Ideally, to conclusively evaluate the impact of livestock a similar study needs to be conducted under condition of extreme drought.

Considering the absence of any large coarse feeder in Gir as well as the substantial contribution of livestock to the lion's diet (Jhala *et al*, unpublished), cattle and buffalo may be fulfilling an important ecological role in the Gir ecosystem. Lion densities and pride sizes were observed to be larger in areas sympatric with livestock (Meena *et al*, 2007, Jhala *et al*, 2006). With a lion focused conservation objective for Gir, maintaining livestock at the current or lower stocking densities may be a good management practice.

Chital were most gregarious ungulates and formed fluid groups (Barrette, 1991) whereas other wild ungulates were generally found in pairs or smaller groups (Table-2.2). Chital group sizes were not observed to increase with increase in density (r = 0.44, p = 0.903) or rainfall (r = 0.097, p = 0.563) in different ecological zones within Gir and therefore result does not support Shankar Raman (1997). However, in this study it seems that the group size corresponds to habitat structure, (explained by Barrette, 1991) and the role of predation (Sharatchandra & Gadgil, 1975; Mishra, 1982; Khan *et al*. 1995). The role of predation in group formation can not be overruled as the lion density in eastern sanctuary is higher than other two zones (Jhala *et al* unpublished data). The group size comparison revealed that habitat structure and the predator density has overwhelming effect on group formation than it's own density and rainfall pattern. The typical and mean group sizes of chital are bigger than Khan *et al* (1995). They pooled all observations of different seasons for the MGS and TGS computation which were significantly different for seasons that resulted into overall decrease in the TGS and MGS. It also seems that disproportionate sampling which includes more observations from vehicle counts than line transects as well as large samples of summer season compared to other seasons. Hence, their results are not bias free, as there is a profound effect of management interferences on group formation of an open

membership group formation species i.e. chital. The managerial practices include provision of artificial water holes and fire lines along the road which in turn provides better water availability and better forage availability. Considering all these fact, it seems more likely that presence of sympatric livestock can not decide the group sizes of chital at landscape level.

The size of a group reflects resource abundance in the habitat (Jarman, 1972). In the case of Gir, larger groups of both chital and sambar were observed in the areas sympatric with livestock. This suggests that in these areas forage availability to wild ungulates was at par or higher in comparison to areas devoid of livestock.

Group sizes of Sambar observed in the current study were similar to those reported by Khan *et al* (1995) for Gir, Karanth & Sunquist (1992) for Nagarhole and Mishra (1982) for Royal Chitwan National Park Nepal. The group sizes of nilgai were also similar to Khan *et al.* (1995) and Dinerstein (1980). Thus it seems that group size in sambar and nilgai are dictated by social organization rather than by resource availability.

The body condition of the chital population of different ecological zones was good for two consecutive years which reflects adequate forage availability during the leanest period of the year throughout the Gir forests. Body condition of tropical ungulates decreases as forage quality and quantity decreases in response to low rainfall (Sinclair, 1977 and Sinclair *et al*, 2000). In case of chital in Gir, change in the body condition was neither correlated with the rainfall gradient (r = 0.785, p = 0.43) nor with the livestock presence (Independent sample t test, t = 0.067, p = 0.949). Hence, the body conditions of chital population do not corresponds to the intensity of livestock grazing at landscape level. The results reject the hypothesis that areas with sympatric livestock population should have poor condition as livestock grazing is believed to detrimental for the quality and quantity of available palatable biomass. In a given condition when quality forage is abundant, environmental and ecological factors likely to override the livestock grazing factor in deciding the chital body condition. Therefore, the negative impact of livestock grazing, if any, is not detectable at landscape level.

It seems likely that chital densities were determined by habitat productivity in a manner to ensure adequate nutrient supply during the leanest

period of the year. The weaker animals (poor condition) were likely to be weeded out by predation in this high predator density forests (Flook, 1970; Jhala, 1991, 1993; Jethva & Jhala, 2004).

2.4.2 Population growth rates: long term cumulative response of environment

The realized rate of increase of a population is the collective response of all individuals in a population to their environment. It is a single parameter that summarizes the population's well being (Caughley, 1977). Most ungulate populations have a potential r_m from 0.16 to 0.22 (Owen-Smith, 2005). The realized *r* for Chital for the past 40 years was much lower than the potential r_m. This could be either due to intra and inter specific competition for limited resources or high rate of predation as Gir has one of the highest densities of large carnivores ever reported with 18 lions and 16 leopards per 100 km^2 forming the major predators (Singh & Kamboj, 1996).

Albeit a five data point calibration for a regression analysis to estimate growth rate is a bare minimum sample size, it is interesting to note that most data point deviate little from the regression line except Khan (1993). Data collected by Khan (1993) was by road counts as was also done by Joslin (1973) and Berwick (1974). However, by 1990 habitat manipulation along tourist paths in the form of a view line, water hole creation, salt licks and fire-line creation were major wildlife management activities. These activities had just commenced or were absent prior to 1970s. Besides, there is a profound effect of sampling design, method and analytical procedure on final outcome of density estimation (Mandujano & Gallina, 1995). Such effects reflect in various density estimation exercises carried out in Gir (Khan, 1997; Goyal *et al*. 2004). Khan (1997) estimated 31.29 wild ungulates km^{-2} on foot transects and 56.2 wild ungulates km^{-2} by vehicle counts. It was evident in this study (Figure -4.4) that road count data can inflate density estimates, primarily due to habitat manipulation activities as seen in Gir west sanctuary an active tourism zone, but can provide unbiased estimates in the absence of such active habitat manipulation. Thus, I believe that density estimates by Khan *et al* (1996) were overestimates. By dropping this dataset from the regression

analysis the estimated *r* value changes little (r = 0.069, R^2 = 0.999, p≤ 0.001, n= 4).

Continued increase in the wild ungulate population in Gir for the past 40 years can probably be attributed to a) Removal of excessive livestock from the protected area, b) Increase in the ungulate carrying capacity of the protected area caused by a major opening up of the canopy by the cyclone of 1983, c) Increased protection from commercial and subsistence level poaching of wild ungulates. With lack of earlier information on competition with livestock, increase in forage availability caused by the cyclone or harvest rates, it is not possible to attribute the continued increase to any one of these factors. It is also possible that all of the three factors may be contributing collectively to the observed rate of increase in wild ungulate density.

2.4.3 The sampling strategy and sample size: *accuracy and precision*

Density estimates for wild ungulates as a whole seemed to stabilize with the sampling of 40 systematically laid line transects of 2-3 km length. The percent coefficient of variation too seemed to stabilize with 30 transects (<20 % CV) with rate of gain in precision being lower as further samples were added. Thus, it is recommend that a minimum of 40 systematic foot transect of 2-3 km long be sampled for effective monitoring wild ungulate densities in Gir Protected Area. For line transect sampling winter (November to February) is the best season in the Gir as due to good dispersal of forage and water the ungulates are well dispersed and not highly clumped as in summer months. Also winter months are better than the monsoon as deciduous trees and shrubs sheds their leaves enhancing visibility and detection on transects (Goyal *et al*. 2004).

2.4.4 Potential competition between chital and livestock

Interspecific competition has to be judged based on two criteria 1) two species compete when they share same resource that is present in short supply, and 2) in using that resource, each species reduces the other's population performance to levels below what these measures would be in the absence of the other species (Vavara *et al*. 1999).

Two crucial issues related to the study of competition between sympatric herbivore populations are: 1) the masking effect of habitat productivity on population demography and 2) the methodological and scale related issue due to spatial resource heterogeneity.

Many studies have explained the regulatory role of food resources in maintaining equilibrium of ungulate density (Bobek, 1977; Sinclair, 1977; Bayliss, 1985; Sinclair, 1985; Skogland, 1985 & 1990, Fryxell, 1987; Dublin *et al.* 1990). However, the plant production in highly variable climate remains unaffected by herbivore density and is largely determined by rainfall, because drought related mortality keeps densities below equilibrium (Ellis & Swift, 1988, Illius & O'Connor, 2000). Due to this overriding effect of climatic variability and subsequent habitat productivity on ungulate density, any negative impact of sympatric livestock on wild ungulate community would be masked.

Hurlbert (1984) commented on the inferences drawn from the unreplicated experiments. Besides, the consideration of spatial heterogeneity in experimental design is essential as it interferes with competition (Powell & Richerson, 1985). To overcome the problem of accidental or chance results in heterogeneous landscape arising due to methodological and scale related issues, the study involved an experimental design with two spatial scale.

In natural environment, the exact control condition is not possible for site specific observations. However, a control site (ecologically similar to intensive study area differing only in terms of livestock grazing) was selected to compare the density, group sizes and body condition of chital population with intensively grazed study area. The result did not show any difference in density group size and body condition between these two sites. The results of the study suggest that there is no negative impact of livestock grazing on population parameters of chital.

However, densities of chital in the areas devoid of livestock were higher at both spatial scales, even though they were statistically insignificant. Though we considered the spatial heterogeneity of the landscape and attempted to capture the long term population response i.e. ungulate density we admit the lack of the temporal scale i.e. replication of the experiment. It is also probable that since the study period covered reasonably good rainfall

years, the short term response of group sizes and body condition of chital did not show any response to sympatric livestock. It is likely that during years of extreme stress such as droughts, food resources may become extremely limiting resulting in competition between livestock and chital. Ideally, to conclusively evaluate the impact of livestock a similar study needs to be conducted which also covers extreme drought condition, to capture the temporal variability in the resource availability in this semi arid landscape.

The results of this study suggest that at the current stocking density of 30.5 livestock per km^2 detrimental effect of livestock to wild ungulate community is undetectable. Considering the absence of any large coarse feeder in Gir as well as the substantial contribution of livestock to the lion's diet (Jhala, unpublished), cattle and buffalo may be fulfilling an important ecological role in the Gir ecosystem. Lion densities and pride sizes were observed to be larger in areas sympatric with livestock (Meena *et al.* 2007, Jhala *et al.* 2006).

The data was collected during normal rainfall years and therefore can not be generalized for extreme conditions as drought which often occurs frequently in semi arid landscape of Gir. Under such drought condition it is entirely possible that growth of annuals (preferred forage, (Chapter - 5) is greatly retarded giving rise to condition for potential competition between wild and domestic ungulates.

CHAPTER 3

Activity and Ranging Patterns of Chital, Cattle and Buffalo

3.1 Introduction

Geist (1974) discussed the logical links between ecology and behavior. Although such links do exist between ecology and behavior, they nevertheless represent distinct realms of natural selection in which social behavior appears as the more conservative element. The ecological variables have primary and secondary manifestations which are either behavior or presumed to affect behavior. Daily patterns of use of time, habitat and food by wild ruminants are related in complex ways to their social, security, comfort and bioenergetic needs. Behaviour is related to day-to-day living aimed to maximize fitness by compromising conflicting needs and to maximize survival and reproductive success by acquiring energy with minimum risk (Renecker & Hudson, 1993).

Ruminants allocate a definite period of time of a day for different activities such as foraging, resting, ruminating, traveling, vigilance, social interactions and on breeding during rutting season. Many factors govern the activity patterns and subsequently the ethology of the taxon; like physiology, anatomy, morphology and environment (Jarman, 1974, Jarman & Sinclair, 1979, Van Soest, 1982, Robbins, 1993, Owen-Smith, 1998). The activity pattern and the time spent for different activities is largely affected by two major factors, the energy demands of the ungulate and the number of constrains that the ungulate encounters (Bunnell & Gillingham, 1985, Lucas, 1987, Bunnell & Harstad, 1989, Dove, 1996).

The specific behaviour or response to the habitat by a particular species can be best understood by monitoring its movement pattern, which ultimately would reflect its behavior or response to the habitat (Rongstad & Tester, 1969; Shea *et al.* 1990). Spatial variation within landscapes results in a heterogeneous distribution of animals' food resources. To exploit these resources animals have to move. The movement strategy that animals use while foraging on spatially dispersed resources is crucial to their success in exploiting food resources (Bell, 1991; Viswanathan *et al.*, 1999; Zollner & Lima, 1999; Bartumeus *et al.*, 2005). Ecologists have therefore invested a lot of effort in quantifying movement patterns of organisms (Turchin, 1998) However, experimental studies of the movement strategy of large mammalian

herbivores are rare (but see Gross *et al.* 1995; Bergman *et al.* 2000; Marell *et al.* 2002).

Most studies in the native range of Chital such as De & Spillett, (1966), Schaller (1967), Prater (1971), Sharatchandra & Gadgil (1975) and as an exotic species by Fuchs (1977) made casual mention of the activity patterns in Chital. However, Graff & Nichols (1966) in Hawaii attempted a general account of routine activities like daily movements, resting, effects of weather on daily movements, seasonal movements etc. Apart from this, very little has been done in studying activity pattern and time budget of chital (de Silva & de Silva, 1992; Sharatchandra & Gadgil, 1980; Tak & Lamba, 1984; Bhat, 1993).

Many previous studies have shown the importance of studying activity patterns of various wildlife species (Walker, 1957; Newton, 1984; Green, 1985; Datta, 1993; Isvaran, 1995). In this study, an attempt was made to quantify the diurnal activity patterns and compute the activity budgets of chital, cattle and buffalo. The activity patterns of these species would reveal the behavioural manifestation of competition between wild ungulate i.e. Chital and domestic ungulates i.e. cattle and buffalo.

3.2 Methods

3.2.1 Activity Pattern

The Scan Animal Sampling technique (Altmann, 1974) was used to investigate the time activity budget, foraging behavior and habitat use of chital, cattle and buffalo from dawn to dusk. Fortunately chital are inclined to be diurnal (Fuchs, 1977) and livestock leave their corals at morning and return in the evening; hence the data collection was carried out during the daytime.

Chital herds in the intensive study area were habituated during reconnaissance study to the continuous presence of the observer in the vicinity. Preliminary observations suggested a scan interval of 10-15 minutes to be appropriate for the study area. The field observations were carried out with the aid of 10×40 binocular or 10× to 35× spotting scope, depending upon the prevailing field conditions. Observations were recorded from 30-50 meter

distance so that focal herd doesn't get disturbed. The behavior states in the present study were grazing, browsing, cud chewing (rumination), standing, lying, moving and the other activities which contributed little (e.g. Social interaction, standing alert etc.). A minimum of seven scan sampling sessions from dawn to dusk (minimum of 12 hrs.) were carried out on chital and livestock herds in each season (two winter, two monsoon and three summer seasons). The focal chital herd was continuously followed on foot from dawn to dusk whereas livestock herd was followed from the *Maldhari* ness while going for their daily foraging till their return to the respective ness at evening. Three *Maldhari* settlements, namely, *Asundrali, Dodhi* and *Leria* and livestock herd of *Tulsishyam* temple were selected within the intensive study area of eastern Gir Sanctuary.

Seasonal activity budgets were computed for chital, cattle and buffalo. The samples for each activity were averaged on a daily basis and their standard error estimated. The detailed activities were merged in to broader activities for seasonal comparisons. Running and walking were merged as 'movement' while 'standing resting' and standing ruminating' were merged as 'standing'. Whereas 'laying resting' and 'laying ruminating' combined to form 'laying'. 'Grazing' and 'browsing' were combined as 'foraging'. The percent activity data was arcsine transformed to make it independent. All three ruminant ungulate species chital, cattle and buffalo were statistically compared and analyzed for different activities and seasons using statistical software SPSS 8.0 (SPSS Inc., 1997). Various statistical tests like Student *t* test, General Linear Model – General factorial (GLM), Duncan, Tukey and Tukey's b multiple range test (Zar, 1984) were used for comparative analysis. Seasonal activity pattern data were pooled for an hourly analysis to observe the temporal overlap in their foraging activity.

3.2.2. Ranging Pattern

Chital herds habituated to human presence around *Maldhari Ness* were followed continuously from early morning to late evening. Observations were recorded from a distance of 10 to 50 m. from the animals. Care was taken to avoid the influence of observer's presence on the natural movement of chital herd. The herd movement was mapped at an interval of 10 minutes

using a hand held Global Positioning System (GPS) unit. Same exercise was also followed for livestock herds of four adjacent settlements of eastern Gir i.e. *Dodhi, Asundrali, Leria* and *Tulsishyam*. A minimum of five days in each season for chital and a minimum of three days for livestock of each of four different *Ness* sites in the intensive study sites were monitored between March 2004 & May 2006.

The grazing circuits were mapped in Arc View GIS (3.2) software; and total distance traveled per sampling day was extracted using 'Animal Movement' function in same software. Mean maximum linear distance traveled from the respective *Ness* site was also calculated to estimate the average foraging radius; and subsequently maximum foraging area for livestock within the intensive study area during different seasons. Diurnal foraging paths of chital and livestock were plotted on high resolution geo-rectified image downloaded from Google Earth@ to overview the seasonal movement in the intensive study area. Total distance moved (TDM) as well as maximum linear distance moved (MLDM) per day was computed for each diurnal forging path of chital and livestock. Total distance moved per day indicates the length of foraging path i.e. movement coupled with foraging whereas, maximum linear distance moved indicates the linear displacement during a day which indirectly indicates the size of foraging area. Both, total distance moved (TDM) and maximum linear distance moved (MLDM) were statistically compared for the seasonal influence on ranging patterns of chital and livestock. Besides, foraging paths of livestock were compared between three ness sites with varying livestock populations.

3.3 Results

3.3.1 Activity Patterns

3.3.1.1 Detailed seasonal activity budgets of chital, cattle and buffalo

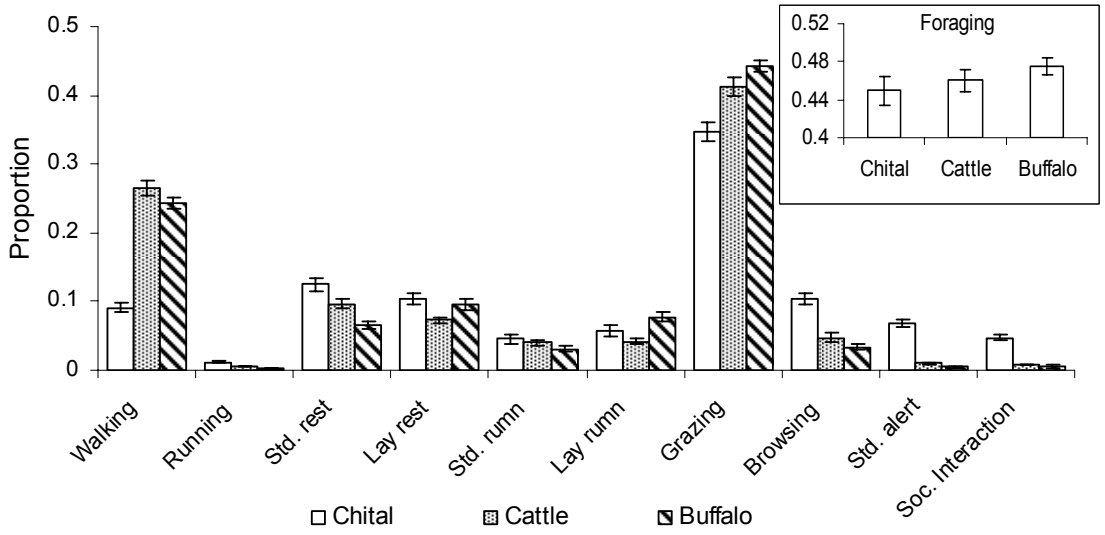
Seasonal activity budgets of chital, cattle and buffalo were computed for their major activity patterns for three seasons i.e. winter, summer and monsoon.

Winter

Among all observed activities during winter across the day length, chital, cattle and buffalo devoted more time on foraging than other activities (chital, 44.95 ± 1.47 %; cattle 46.05 ±1.13 %; buffalo, 47.56 ± 0.94 %). "Foraging" as a whole includes "grazing" as well as "browsing". Among livestock i.e. cattle and buffalo, "walking" is the second major activity after "foraging" whereas in chital, "resting" ("standing resting" as well as "laying resting") was the next major activity after "foraging". The striking difference between chital and livestock was observed in the time spent in "social interactions" and "standing alert" i.e. vigilance. Chital was observed spending significant time on "browsing" compared to cattle and buffalo (Figure-3.1).

One way ANOVA of arcsine transformed proportion data for time spent on four broad activities i.e. standing, moving, laying and foraging by chital, cattle and buffalo showed that proportion of time spent by these large herbivores on various activities was different (One way ANOVA, chital: $F = 19.65$, $p \leq 0.001$; cattle: $F = 140.17$, $p \leq 0.001$; buffalo: $F = 128.28$, $p \leq 0.001$). Chital spent more time on 'laying' and 'foraging' than 'standing' or 'walking' (*Homogeneous subsets, Tukey HSD at* $p \leq 0.05$). Whereas, cattle spent maximum time on 'walking' and 'foraging' followed by 'standing' and 'laying' (*Homogeneous subsets, Tukey HSD at* $p \leq 0.05$). In case of buffalo, time spent on 'foraging' was maximum followed by 'laying' and 'walking', while time spent on 'standing' was the least among all activities (*Homogeneous subsets, Tukey HSD at* $p \leq 0.05$).

Figure- 3.1: Detailed activity budgets of chital, cattle and buffalo for winter (2005 & 2006) in eastern Gir sanctuary. Inset shows the comparative proportionate time spent in foraging activity (grazing and browsing). Errors bars are standard errors.

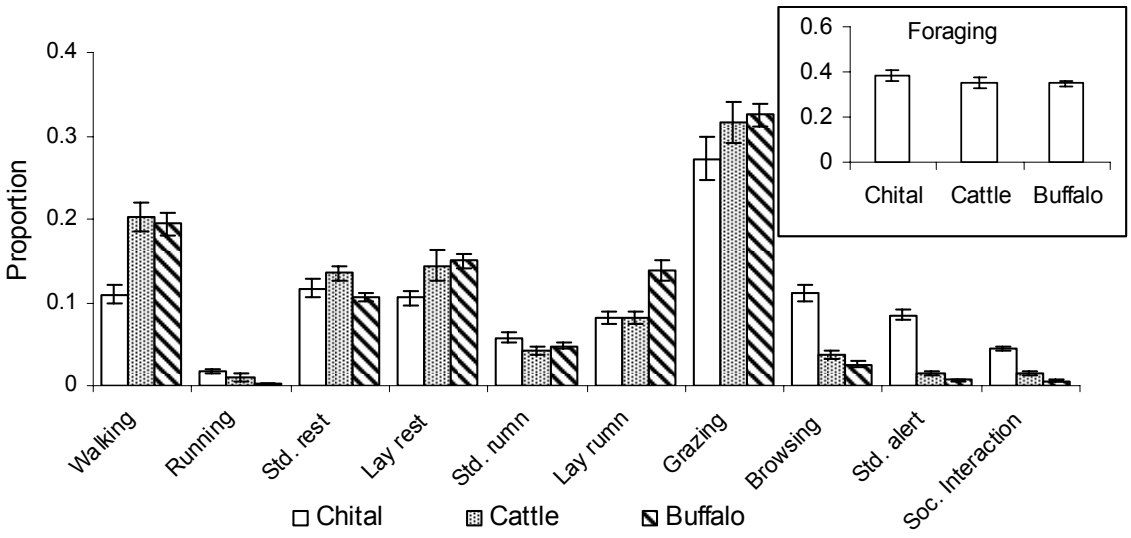


Summer

Likewise winter, foraging was the major activity observed for chital, cattle and buffalo during summer (Figure -3.2). The contribution of "browsing" in total foraging activity was observed to be increased compared to winter months. "Resting" ("Standing resting" as well as "laying resting") was the second major activity during summer. All three ruminants were used to spend prolonged time on ruminating during afternoon hours of hot summer season (Figure -3.2). Besides, chital spent relatively more time on vigilance i.e. "standing alert" (8.5 ± 0.57 %) compared to other seasons i.e. winter and monsoon.

One way ANOVA of arcsine transformed proportion data for time spent on four broad activities i.e. standing, moving, laying and foraging by these large herbivores showed no difference in activity pattern between any of these animal species during summer (One way ANOVA, chital: $F = 134.64$, $p \leq 0.001$; cattle: $F = 268.95$, $p \leq 0.001$; buffalo: $F = 348.17$, $p \leq 0.001$). Unlike winter, maximum time was spent on foraging compared to rest of the activities by chital, cattle and buffalo (*Homogeneous subsets, Tukey HSD at* $p \leq 0.05$).

Figure- 3.2: Detailed activity budgets of chital, cattle and buffalo for summer (2004, 2005 & 2006) in eastern Gir sanctuary. Inset shows the comparative proportionate time spent in foraging activity (grazing and browsing). Error bars are standard errors.

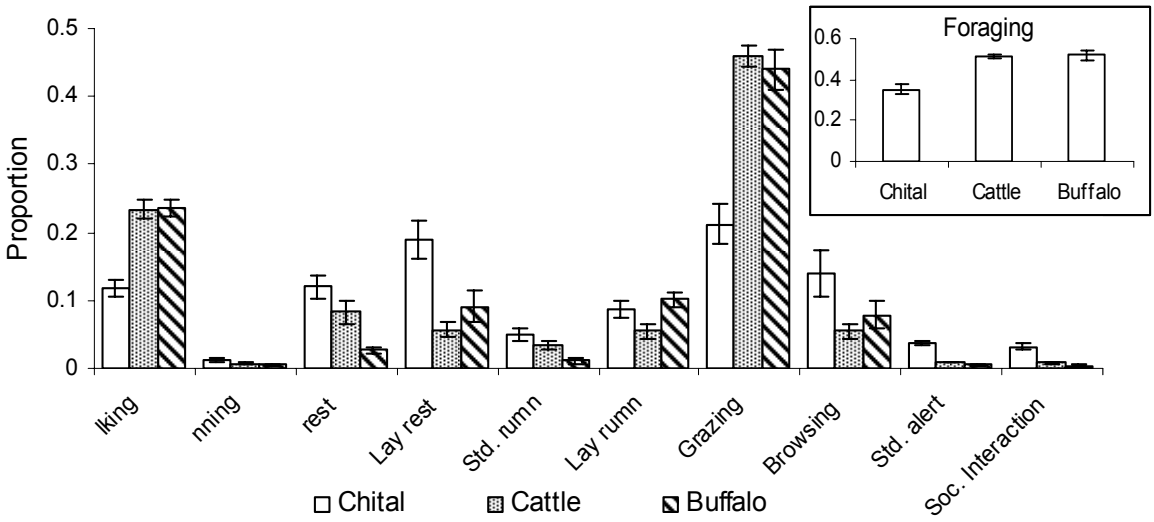


Monsoon

Though, "foraging" was the major activity of these three animal species, the overall contribution of "foraging" to the total time spent on various activity of chital was less compared to other two seasons. Unlike chital, the total contribution of time spent in foraging to the activity of livestock was highest (>50 %) during monsoon compared to other two seasons (Figure - 3.3). Social interaction was minimal during monsoon in all three species. Chital spent relatively more time resting compared to winter and summer. Unlike chital, cattle and buffalo spent relatively less time resting during monsoon.

Similar to previous two seasons, these animal species spent time on various activities was different (One way ANOVA, chital: $F = 47.04$, $p \leq 0.001$; cattle: $F = 42.71$, $p \leq 0.001$; buffalo: $F = 53.97$, $p \leq 0.001$). Compared to previous seasons, time spent by chital on 'foraging' and 'laying' decreased while, time spent on 'moving' and 'standing' increased, nonetheless time spent on 'foraging' was maximum (*Homogeneous subsets, Tukey HSD at* $p \leq 0.05$). However, time spent on various activities, except foraging, by cattle was not different during monsoon (*Tukey HSD Posthoc test*, $p = 0.59$). Whereas in case of buffalo, time spent on 'laying' was higher than 'moving' and 'standing' but lower than 'foraging' (*Tukey HSD Posthoc test*, $p \leq 0.05$).

Figure- 3.3: Detailed activity budgets of chital, cattle and buffalo during Monsoon (2004 & 2005) in eastern Gir sanctuary. Inset shows the comparative proportionate time spent in foraging activity (grazing and browsing). Error bars are standard errors.

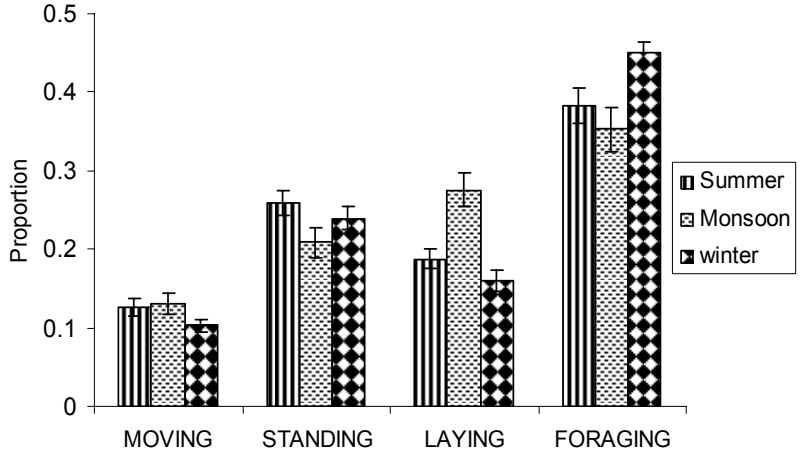


3.3.1.2 Comparison of broad seasonal activity patterns of chital cattle and buffalo

Chital

The comparison for broad activity patterns i.e. “Foraging”, “Moving”, “Standing” and “Laying”, for different seasons reveals that proportional time spent for foraging is higher during winter (45 ± 1.5%) (Figure- 3.4), while time spent on standing was higher (25.9 ± 1.5 %) during summer. The ‘movement’ was lowest during winter (10.2 ± 0.7 %). Chital spent relatively more time on laying during monsoon compared to other two seasons.

Figure- 3.4: Seasonal comparison of broader activity patterns of chital in eastern Gir sanctuary. Error bars are standard errors.



Cattle and Buffalo

There was no major difference was observed in activity pattern between cattle and buffalo as they go as a common herd. The major difference between these two sympatric species was observed during resting times in afternoon hours, where buffalo spent more time in laying in water pools (28.8 ± 1.7 % in summer, 19.2 ± 2.2 % in monsoon and 17.4 ± 0.9 % in winter) while, cattle generally stand in shady areas (19.2 ± 1.4 % in summer, 14.8 ± 0.8 % in winter and 12.5 ± 1.9 % in monsoon). Buffalos and cattle were found spending less time on movement (19.5 ± 1.3 %, 21.3 ± 1.5% respectively) in summer compare to monsoon (24.1 ± 1.3 %, 24.2 ± 1.2 % respectively) and winter (24.6 ± 0.8 %, 26.9 ± 1.1 %). Movement was maximum during winter (26.9 ± 1.1 % in cattle and 24.6 ± 0.8 % in buffalo) and minimum during summer (21.3 ± 1.5 % in cattle and 19.5 ± 1.3 % in buffalo (Figure - 3.5 & 3.6).

Figure- 3.5: Seasonal comparison of broader activity patterns of cattle in eastern Gir sanctuary. Error bars are standard errors.

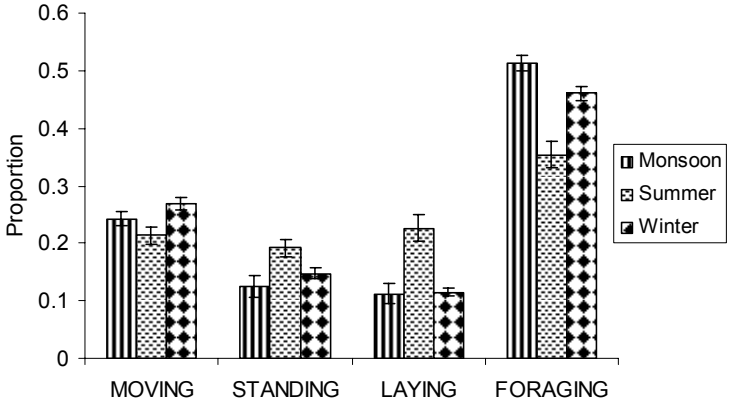
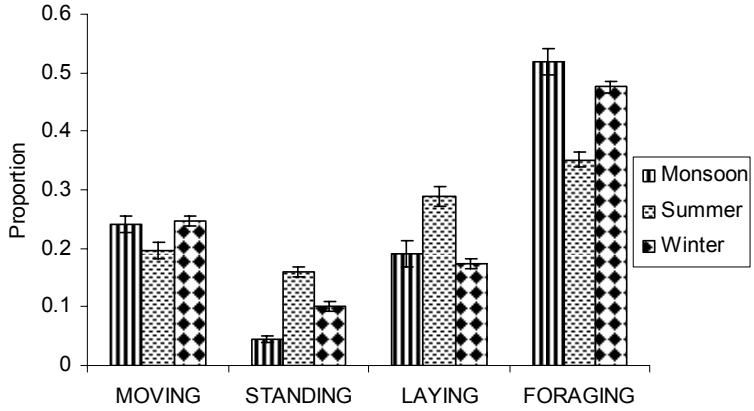


Figure- 3.6: Seasonal comparison of broader activity patterns of buffalo in eastern Gir sanctuary. Error bars are standard errors.

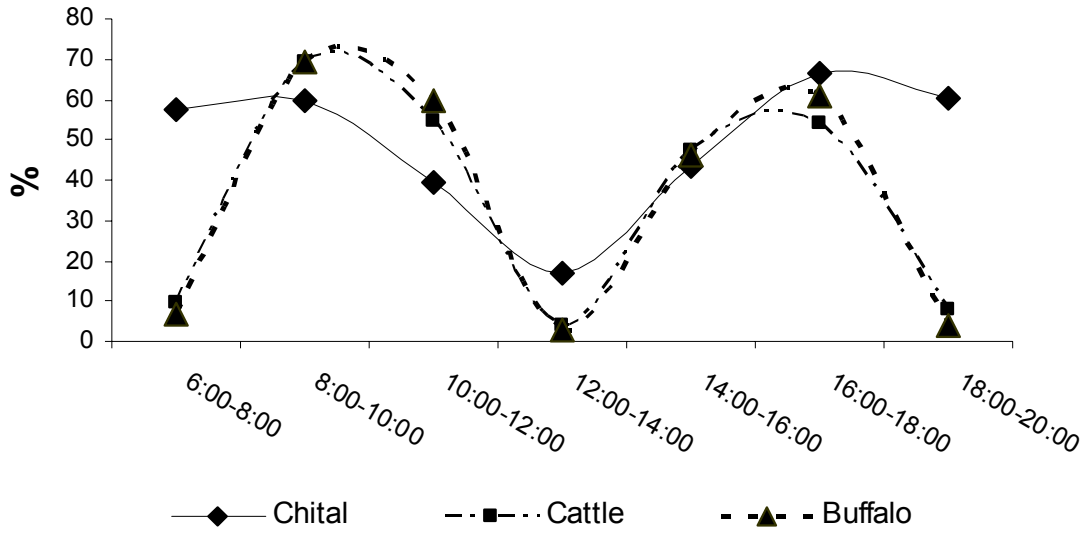


3.3.2 Temporal activity patterns of chital and livestock

Winter

Two distinct foraging peaks were observed for chital and livestock population, one in morning and second in late afternoon. In livestock, morning foraging peak was larger than evening as 69.14 ± 3.43 % cattle and 69.13 ± 2.68 % buffalos were engaged in foraging compared to 59.58 ± 3.39 % time spent foraging by chital during morning. Contrary to livestock, evening foraging peak of chital was larger (66.59 ± 3.01 %) compared to morning peak. Foraging peaks of chital are more diffused and prolonged compared to cattle and buffalo as chital were observed foraging till late evening and start foraging well before sunrise, while livestock start later and also return earlier to their respective corrals in the *Ness*, due to threat of lion predation. During afternoon hours, almost all cattle and buffalos were seen resting and other activities. However, chital continues foraging in afternoon hours although, not more than 20 % individuals observed engaged in the foraging activity (Figure-3.7).

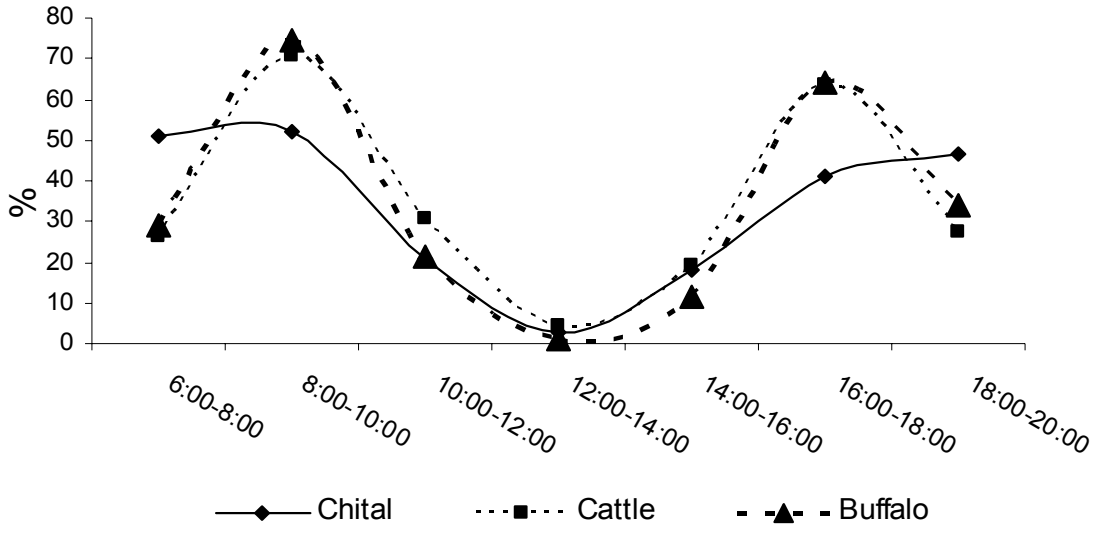
Figure- 3.7: Temporal foraging pattern of chital, cattle and buffalo during winter (2005 -06) in eastern Gir sanctuary.



Summer

During summer, chital foraging peaks were prolonged while livestock foraging peaks were narrower compared to winter (Figure-3.8). Livestock also start foraging earlier compared to winter as more than 20 % individuals were always engaged in foraging except afternoon hours. Like cattle and buffalo, chital foraging activity also drops from 52.19 ± 4.21 % in morning to 2.51 ± 0.8 % during afternoon hours. Among livestock foraging pattern remains almost same to winter pattern i.e. larger morning peak compared to evening peak but in chital morning peak appears larger than evening peak unlike winter pattern (Figure-3.7). However, evening foraging peak of chital was prolonged as 46.37 ± 8.36 % individuals were still foraging even after darkness and therefore further observation was prevented. Though the temporal pattern of foraging is similar, chital foraging was more concentrated in early morning and late evening hours. Evening foraging peak was observed later than livestock foraging peak. Hence, very little temporal overlap occurred in foraging pattern between chital and cattle-buffalo.

Figure- 3.8: Temporal foraging pattern of chital, cattle and buffalo during summer (2004, '05 & '06) in eastern Gir sanctuary.

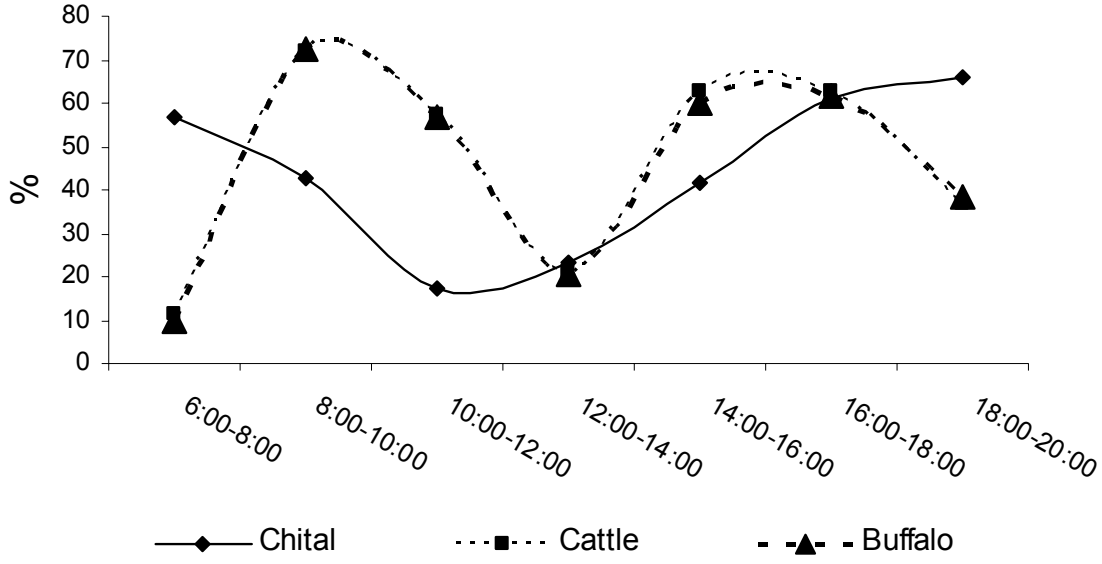


Monsoon

During monsoon, no prominent foraging peak for chital was observed in afternoon. After a early drop in the foraging activity in late morning hour, it slowly increases till evening. Evening foraging peak is not conspicuous in chital. Even in livestock foraging peaks are broader with small resting period

in afternoon hours. Besides more than 20 % livestock kept foraging during afternoon too. Evening foraging peak in livestock was also diffused compared to other two seasons as 38.19 ± 13.16 % livestock were still engaged in foraging in late evening hours. Almost no temporal overlap was observed in foraging activity between chital and cattle-buffalo as a major shift in the peak foraging period was observed in chital during monsoon (Figure- 3.9).

Figure- 3.9: Temporal foraging pattern of chital, cattle and buffalo during monsoon (2004 & '05) in eastern Gir sanctuary.



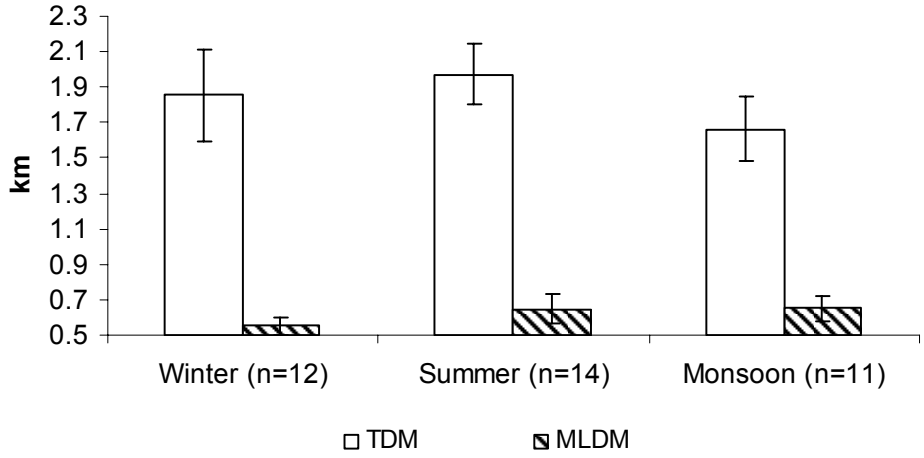
3.3.3 Ranging Pattern

3.3.3.1 Seasonal Ranging Pattern of Chital

The average total length of the chital foraging path (which is also referred to as TDM i.e. Total Distance Moved) was 1.77 ± 0.10 km (n= 37) per day across three different seasons. The total length of the chital foraging path ranged from 0.84 km in Monsoon to 3.07 km in summer. The average Maximum Linear Distance Moved (MLDM) per day was 0.60 ± 0.04 km (n = 37) irrespective of season. The maximum linear distance moved in a day ranged from 0.28 km in winter to 1.27 km in summer (Table-3.1). Figure- 3.10 shows that average total length of foraging path and mean maximum linear distance moved per day were higher during summer. However, there was no significant seasonal difference observed in either average length of diurnal foraging path (One way ANOVA, F = 0.123, p= 0.304) or average maximum linear distance moved per day (One way ANOVA, F = 1.15, p= 0.329). There

was a correlation between the total length of foraging path and mean maximum distance moved per day during all seasons (Pearson's correlation, r = 0.768, p ≤ 0.001), however, the correlation was weaker during monsoon (Pearson's correlation, r = 0.587, p = 0.057).

Figure- 3.10: Average length of daily foraging paths (TDM) and mean maximum distance (MLDM) traveled per day by chital during three seasons in intensive sites of eastern Gir sanctuary. Error bars are standard errors.



Winter

During winter, average total length of foraging path (TDM) for chital was 1.62 ± 0.18 km per day while mean maximum linear distance moved (MLDM) by chital was 0.51 ± 0.05 km per day (Table- 3.1). The TDM and MLDM for chital ranged from 0.86 to 2.42 km and from 0.28 to 0.87 km, respectively. Both the distances i.e. TDM and MLDM were found to be least during winter, compared to summer and monsoon (Table- 3.1) which suggests comparatively better forage availability and opportunity during winter. However, there was very small difference in the median observations of MLDM between winter (0.55 km) and summer (0.53). Chital movement pattern during winter is shown in Figure - 5.11. It was observed that during winter, chital moved more in comparatively open habitat.

Figure- 3.11: Daily foraging paths of chital during winter plotted on Google Earth@ image of intensive sampling site in eastern Gir sanctuary.

Summer

The average total length of foraging path i.e. TDM (1.97 ± 0.17 km) was comparatively more than what was observed during other two seasons i.e. winter and monsoon (Table- 3.1). Similarly mean maximum linear distance moved by chital during summer (MLDM) was higher (0.65 ± 0.09) than winter but same in monsoon; nonetheless the median observation of maximum linear distance moved was least during summer amongst all three seasons (Table-3.1). The TDM and MLDM were ranging from 1.11 to 3.07 km and 0.3 to 1.27 km, respectively. Diurnal movement pattern of chital during summer is shown in Figure - 3.12. It was observed that chital moved along the dense moist mixed habitats found along the drainages. During this resource crunch period sometime chital herd was found traveling up to 3.0 km from morning to evening.

Table- 3.1: A comparative summary of total distance moved (TDM) i.e. Length of the foraging path as well as mean maximum linear distance traveled per day (MLDM) by chital and *Maldhari* livestock during three different seasons.

	Winter				**Summer**				**Monsoon**			
	Chital		Livestock		Chital		Livestock		Chital		Livestock	
	TDM	MMDM	TDM	MMDM	TDM	MMDM	TDM	MMDM	TDM	MMDM	TDM	MMDM
Mean (±SE)	1.62 (± 0.18)	0.51 (± 0.05)	5.8 (± 0.22)	1.90 (± 0.12)	1.97 (± 0.17)	0.65 (± 0.08)	6.35 (± 0.39)	2.13 (± 0.18)	1.66 (± 0.18)	0.65 (± 0.08)	7.46 (±0.33)	2.63 (± 0.16)
Standard deviation	0.64	0.19	1.12	0.60	0.65	0.32	1.82	0.86	0.60	0.25	1.20	0.59
Median	1.61	0.55	5.72	1.85	1.78	0.53	6.37	2.12	1.55	0.68	7.7	2.62
Range	1.56	0.59	4.44	2.32	1.96	0.97	7.24	2.92	1.72	0.67	3.69	2.46
Min-Max	0.86 - 2.42	0.28 - 0.87	4.12 - 8.57	1.1 - 3.42	1.11 -3.07	0.3 -1.27	2.67 - 9.91	1.1 - 4.02	0.83-2.56	0.32 -0.99	5.53 - 9.23	1.48 - 3.94
n	12	12	26	26	14	14	22	22	11	11	13	13

Figure- 3.12: Daily foraging paths of chital during summer plotted on Google Earth@ image of intensive sampling site in eastern Gir sanctuary.

Monsoon

During monsoon, the average total length of the chital foraging path (TDM) was 1.66 ± 0.18 km per day while, mean maximum linear distance moved per day (MLDM) was 0.65 ± 0.08 km. Both the distances i.e. TDM and MLDM decreased compared to previous season i.e. summer. The TDM and MLDM were ranging from 0.83 to 2.56 km and 0.32 to 0.99 km per day during monsoon. Interestingly, during this season, the median TDM was observed to be smallest but the median MLDM was largest amongst all seasons (Table-3.1). The movement pattern of chital is shown in Figure -3.13. Chital herds were observed to be moving in the open habitat along the edges of the dense covers. Due to the presence of free water everywhere their movement was not restricted around water holes and could moved more linearly in search of better foraging opportunities.

Figure- 3.13: Daily foraging paths of chital during monsoon plotted on Google Earth @ image of intensive sampling site in eastern Gir sanctuary.

3.3.3.2 Seasonal Ranging Patterns of Livestock

The average foraging path of livestock irrespective of seasonal variation was 6.35 ± 0.2 km, ranging from 2.67 km in summer '05 for *Leria* herd to 9.91 km in summer '04 for *Asundrali* herd. The Mean Maximum Linear Distance Moved (MLDM i.e. average maximum linear distance from respective *Maldhari* settlement) was 2.14 ± 0.1 km. However, MLDM ranged from 1.1 km during winter for *Leria* herd to 2.04 km during summer for *Asundrali* herd. Figure -3.14, 3.16 & 3.18 show the average total length of livestock foraging paths as well as mean maximum linear distance traveled from respective *Maldhari Ness* site during winter, summer and monsoon.

The TDM and MLDM were correlated throughout the study period (Pearson's correlation, r = 0.763, $p \leq 0.001$) however the correlation was stronger during summer (Pearson's correlation, r = 0.80, $p \leq 0.001$). Unlike chital, both the distances i.e. TDM and MLDM were significantly different during different seasons (TDM: ANOVA, F= 5.797 $p \leq 0.01$; MLDM: ANOVA, F= 6.92, $p \leq 0.005$). The average total lengths of foraging path as well as mean maximum linear distance moved per day were higher during monsoon compared to winter and summer (*Posthoc Tukey HSD test*, $p \leq 0.05$).

Besides, the average total length of foraging path (TDM) was significantly different for different *Maldhari Nesses* (One way ANOVA, F= 3.345 $p \leq 0.05$), although the mean maximum linear distance was not significantly different for livestock population sizes i.e. *Maldhari Nesses* (One way ANOVA, F= 0.764, p = 0.471).

Winter

The pattern of livestock movement during winter is shown in the Figure- 3.15. During winter, average (± SE) total length of the foraging paths (TDM) and mean maximum linear distance (MLDM) were 5.8 (± 0.22) km and 1.9 (± 0.12) km, respectively. The TDM and MLDM ranged from 4.12 to 8.57 km and 1.1 to 3.42 km, respectively (Table- 3.1). The average length of the foraging path and maximum distance traveled away from the respective *Ness* site (MLDM) was least during winter compared to summer and monsoon (Figure- 3.14). The mean maximum linear distance traveled from the

respective Ness was not significantly different between *Nesses* (One way ANOVA, F =1.5, p = 0.257). The average lengths of daily foraging paths were marginally different for different *Maldhari* settlements (One way ANOVA, F = 3.35 p = 0.06). The average TDM by livestock herds of *Leria* was significantly smaller than *Dodhi* (*Posthoc Tukey HSD test*, p = 0.06) and but not significantly different from *Asundrali* livestock herds (*Posthoc Tukey HSD test*, p =0.823).

Figure- 3.14: Average length of daily foraging paths (TDM) and mean maximum linear distance traveled (MLDM) by *Maldhari* livestock herds from three different Ness sites during winter. Error bars are standard errors.

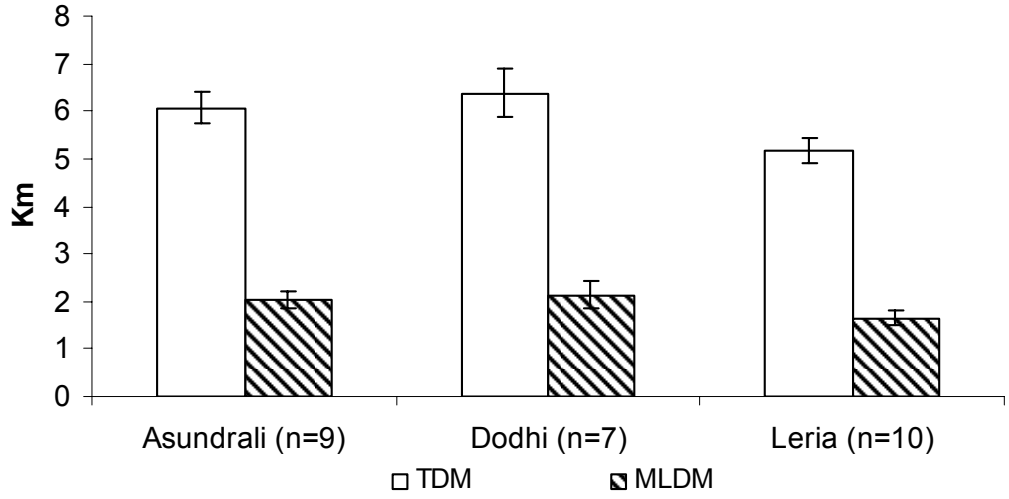


Figure- 3.15: Daily foraging paths of livestock form three *Nesse*s in Gir East during winter plotted on Google Earth image of the intensive sampling site of eastern Gir sanctuary.

Summer

During summer, average length of the foraging path (TDM) and mean (± SE) maximum linear distance moved (MLDM) per day were 6.35 (± 0.39) km and 2.13 (± 0.18) km, respectively. The TDM and MLDM were ranging from 2.67 to 9.91 and 1.1 to 4.04 km, respectively (Table- 3.1). The movement pattern of different livestock herds of three *Maldhari Nesses* during summer is shown in the Figure- 3.17. The average TDM was larger for *Dodhi* livestock herd, during summer. However, the average MLDM was larger for *Asundrali* livestock (Figure- 3.16). Although, none of these distances were significantly different between different *Ness* sites (ANOVA, TDM: F = 2.392, p = 0.118; MLDM: F = 1.169, p = 0.332).

Figure- 3.16: Average length of foraging paths (TDM) and mean maximum linear distance traveled (MLDM) by *Maldhari* livestock herds from three different Ness sites during summer. Error bars are standard errors.

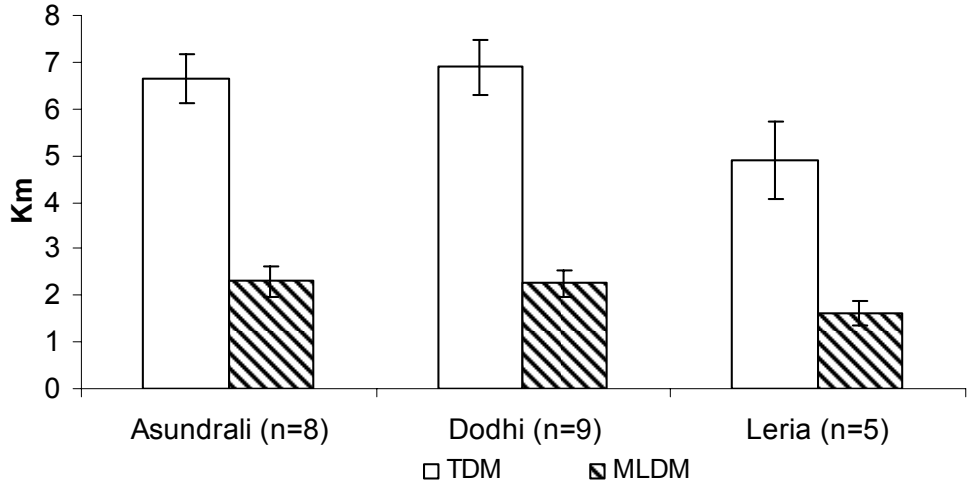


Figure- 3.17: Daily foraging paths of livestock form three *Nesse*s in Gir East during summer plotted on Google Earth image of the intensive sampling site of Gir East.

Monsoon

During monsoon, average (± SE) length of the foraging path (TDM) and mean maximum linear distance moved (MLDM) per day of livestock were 7.46 (± 0.33) km and 2.63 (± 0.16) km, respectively (Table- 3.1). Both the distances i.e. TDM and MLDM were highest during monsoon compared to winter and summer seasons (Figure – 3.16). The TDM and MLDM ranged from 5.53 to 9.23 km and 1.48 to 3.94 km, respectively. During monsoon too, TDM and MLDM were not significantly different between different *Maldhari Nesses* (ANOVA, TDM: F= 0.395, p = 0.682; MLDM: F = 1.709, p = 0.22). The movement patterns of livestock during monsoon are shown in the Figure-3.19.

Figure- 3.18: Average length of foraging paths (TDM) and mean maximum linear distance traveled (MLDM) by *Maldhari* livestock herds from three different Ness sites during monsoon. Error bars are standard errors.

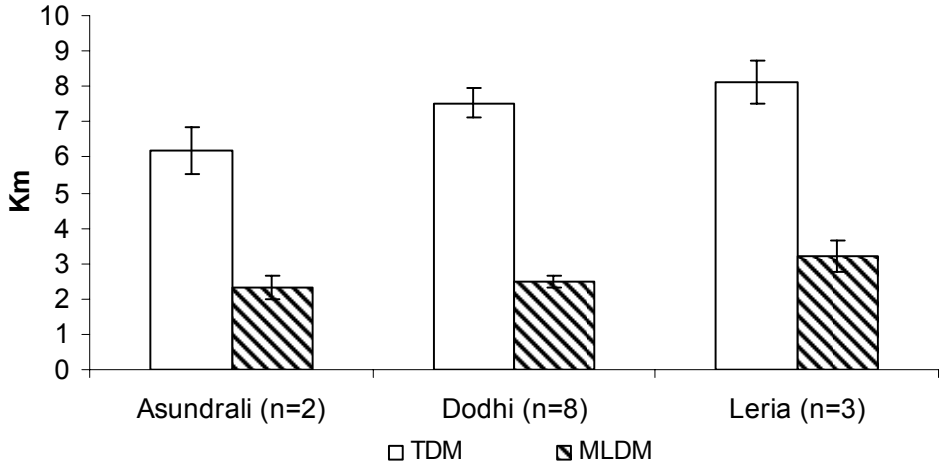


Figure- 3.19: Daily foraging paths of livestock form three *Nesse*s in Gir East during monsoon plotted on Google Earth image of the intensive sampling site of Gir East.

3.4 Discussion

Chital and livestock spent considerable amount of time (< 30 %) on the foraging in all three seasons. It is generally assumed that the presence of sympatric livestock causes depletion of foraging resources of wild ungulates. The theoretical (Emlen, 1966; Schoener, 1971) and empirical (Homewood, 1978) studies qualifies a habitat resource poor if animals spend more time foraging but in this case the time spent in foraging is comparable with earlier studies elsewhere (Jarman & Jarman, 1973; Arnold, 1985; Bunnell & Gillingham, 1985; Owen-Smith, 2002) and in the livestock free area, in India (Priyadarshini, 2005).

3.4.1 Chital foraging

The proportion of 'grazing' was higher compared to 'browsing' in overall foraging activity of chital in all seasons. (Consideration of two foraging modes i.e. grazing and browsing was based on the position of animal's mouth while foraging, rather than food items viz. graze or browse items.). The activity budgets during three seasons i.e. monsoon, winter and summer, revealed that chital feeds more on food items available on forest floor (fruits, pods and leaves along with grasses and forbs). The forest floor is well covered with palatable grasses and herbs during winter which offers wide preference of forage species to chital. The rainfall in monsoon months accelerates the vegetative growth of tree species which makes new tender shoots of nutritionally rich browse species available to herbivores. This subsequently causes the increased browsing during monsoon. Hence during monsoon this difference between grazing and browsing is lowest i.e. browsing proportion increases comparatively.

The time spent in foraging was highest during winter as compared to summer and monsoon as winter is the fawning period for chital and hence females need nutritious forage to bring up new born fawns and also build up body reserve for the lean summer (Robbins, 1993) (Figure - 3.4). The effects of increased energy demand on females during summer and monsoon are unknown. However, nutritional stress during lactation i.e. winter negatively affects offspring fitness and future reproduction (Maynard *et al*. 1979).

Increased feeding during the winter can be viewed as a 'relative increase', as ungulates restrict their movement and conserve energy by lowering activity rates and time searching for food during harsh weather condition.

Fawning occurs during winter when interactions between doe and fawn were observed maximum. While, rutting peak of chital was observed during summer, when male-male and male- female interactions are frequent which reflects in the proportion time spent in social activity during winter and summer. During monsoon male chital are found in velvet when they avoid conflict with other males and remain isolated from mixed herds and therefore less social interactions were observed.

Chital were found more alert and spending relatively more time on 'standing' during summer as they spend much time in dense moist mixed vegetation patches to avoid the extreme hot temperature during late morning to late afternoon hours. The chances of predator presence are also high in dense thickets of riverine habitat hence standing position seems safer to escape from such sudden attack from lion and leopard. The 'movement' was observed to be lowest during winter as forage availability is good compared to summer and monsoon. The time spent on foraging was reduced as an energy saving strategy. Where as during monsoon they rest in open shady areas where they can sense predator from safe distance.

3.4.2 Livestock foraging

No major difference was observed in activity pattern between buffalos and cattle as they go as a common herd for foraging. The difference between cattle and buffalo was observed during resting time in afternoon hours, where buffalos spend more time in wallowing and resting in watery places while cattle generally stand in shady areas (Figure 3.1, 3.2 & 3.3).

Limiting factor for their movement could be the availability of water, extreme temperature and low forage quality during summer months might compel them to conserve energy by moving less. Also low forage quality and quantity during summer might take more time for gut passage for ruminant herbivores. Buffalo was observed mostly grazing and occasionally browsing through out all seasons. Cattle were also found to graze by and large but comparatively they spent more time on browsing than buffalos. Browsing

proportion was high during monsoon after rainfall for both of the domestic ungulates, as new browse becomes available after rainfall and *Maldharis* lopped good quality browse to feed their livestock. As buffalos are more susceptible to heat, they spent afternoon hours resting, either sitting or standing, in water.

3.4.3 Comparative foraging strategies of chital and livestock

Interspecific behavioral hierarchies are a possible way by which species partition resources (Morse, 1974). Because body size influences dominance among species of the same trophic level (Fisler, 1977), one must suspect that in areas where exotic species have become established they have either monopolized resources directly from smaller native species or caused smaller species to shift niches.

The temporal activity patterns from morning to evening involved two foraging peaks for chital as well as livestock. Most studies on ungulates reported distinct foraging peaks in a daily cycle with an intensive peak during morning hours (Schaller, 1967; Jarman & Jarman, 1973; Klein & Fairall, 1986; Twine, 2002). The broad patterns of alternating foraging and resting ruminating were almost similar across the seasons for these sympatric animals. However, some shift in this pattern was observed between seasons. All the observations from all three seasons show that chital forage for longer duration compared to livestock and hence the foraging peaks are rather diffused during morning as well as afternoon hours. The difference in the foraging patterns could be attributed to the size, quality and quantity of the food items; gut capacity and process; and digestion of the forage (Bell, 1970; McNab, 1980; Van Soest, 1982, Demment & Van Soest, 1985). Livestock were bulk and coarse feeder (Chapter –5) with larger gut capacity hence they try to maximize on foraging time during their time bound foraging period as they are driven by herd keepers and spent a definite amount of time on rumination during fixed afternoon hours. While chital foraging activity neither crossed beyond 50 % nor went down below 30 % during whole day length except summer. This could be well attributed to relatively small gut size, feeding style (chapter – 5), and digestion physiology of chital (Bunnell & Gillingham, 1985; Robbins, 1993; Schmidt-Nielsen, 1997).

The foraging activity of chital and livestock was well synchronized with the daylight (Jarman & Jarman, 1973) and the ambient air temperature (Schmidt-Nielsen, 1972, Taylor, 1972) in all three seasons. However, monsoon foraging patterns of chital as well as livestock were quite distinct compared to other two seasons due to cloudy overcast and significant drop in the air temperature. Hence during monsoon there is no clear resting period in either chital or livestock as evident from previous studies on tropical ungulates (impala: Jarman & Jarman, 1973; greater kudu: Owen-Smith, 1998; black wildebeest and blesbok: Twine, 2002). Livestock showed a diffused pattern in both the foraging peaks, whereas chital foraging was almost continuous throughout the day.

On a few occasions, direct interactions between chital and livestock were observed however, no interspecific aggression was noticed. In such instances, chital herd used to flee away, which shows the dominance of the livestock species due to their larger body sizes and human escorts. However, behavioral dominance probably plays a minor role, if any, in niche partitioning because of differences in habitat selection between chital and livestock. In summary, individuals of species of larger size have a spatial advantage as they are rarely displaced by small body size species, but whether such net gains are turned into reproductive benefit is doubtful (Berger, 1995).

3.4.4 Ranging patterns of chital and livestock

Bailey *et al*. (1996) observed that the grazing distribution patterns of large herbivores are affected by abiotic factors such as slope and distance to water and by biotic factors such as forage quantity and quality. The major abiotic factor determining the large-scale distribution patterns of large herbivores especially, chital and livestock was the water availability and terrain. Such abiotic factors act as constraints within which mechanisms involving biotic factors like forage quality and quality operate. Although livestock roamed quite large area everyday, their movement was restricted by water availability, whereas chital generally stayed nearby water sources.

Cohen *et al*. (1989a & 1989b) found that white tailed deer traveled farther during the resource crunch condition which lends support to the findings of this study. Both, chital and livestock traveled more during summer

compared to winter and monsoon. During summer, increased walking by livestock appeared to be at the expense of foraging time, since other activities did not changed much during this period.

The shape of movement paths is a fundamental determinant of the efficiency of movement strategies (Bartumeus *et al.* 2005). Animals foraging in an area with high food abundance have a lower net displacement and decrease the chance of leaving the high resource density area, thereby increasing the utilization of resources (Kareiva & Odell, 1987; Turchin, 1991; Focardi *et al.*, 1996; Bartumeus *et al.*, 2005). During this study also, the movement patterns of chital and livestock during different seasons i.e. different resource abundance showed that the total displacement i.e. maximum distance traveled per day by both, chital and livestock was minimum during winter (Table-3.1), whereas the movement patterns of both involved long straight foraging paths during summer. When resources become scarce i.e. summer, straighter and faster movements become more efficient than highly tortuous ones, as they result in high net displacement, thereby minimizing the chance of revisiting an already visited resource and increasing the chance of finding new resources (Turchin, 1991; Crist *et al.*, 1992; McIntyre & Wiens, 1999; Viswanathan *et al.*, 1999; With *et al.*, 1999; Zollner & Lima, 1999; Bartumeus *et al.*, 2005).

Most of the past studies used random movement strategy while foraging within the theory of optimal foraging (Pyke, 1984; Cain, 1985; Viswanathan *et al.*, 1999; Zollner & Lima, 1999; Bartumeus *et al.*, 2005) because information on resource distribution is considered to be limited in animals (Bell, 1991). However, Bailey *et al.* (1996) observed that prior information on the resource distribution transforms in to a definite shape of animal foraging paths which increases their chances of encountering the targets. During this study, the shape of the foraging paths of chital shows that probably animals know the resource distribution in the area and that prior information helped increasing their chances of encountering the food patches.

Some studies show that some movement patterns are more successful in finding resources than others. In the search for single targets that are depleted after encounter, straight line searches are most efficient (Pyke, 1984; Viswanathan *et al.*, 1999; Zollner & Lima, 1999; Bartumeus *et al.*,

2005). However, movement patterns of chital and livestock seemed to involve multiple targets with a patchy distribution. Hence, combinations of frequent short with occasional very long straight searches were observed which maximizes the searching efficiency (Viswanathan *et al.*, 1999).

CHAPTER 4

Habitat Use and Selection by Chital and Livestock

4.1 Introduction

For the effective management and conservation of a species or group of species their specific habitat requirements need to be determined (Eisenberg & Seidensticker, 1976). Free-ranging herbivores have to make many foraging decisions at different resolution levels (Senft *et al.* 1987; Stuth, 1991) resulting in a foraging strategy that meets the specific nutrient and energy requirements of large herbivores that ultimately determines differential habitat selection by them. Habitat use is an outcome of the foraging strategy of the herbivores; it is the expression of the way in which grazing animals resolve the conflict between their need for food and their intrinsic and extrinsic constraints (Illius & Gordon, 1993).

Differential resource selection is one of the principle factors which permit species to coexist. Habitat selection by ungulates is a function of several factors, amongst which food availability, mate availability and predation are of major importance (Jarman, 1974). The habitat use patterns of ungulates change between seasons due to a number of environmental factors (Shannon *et al*. 1975). Besides this, body size dependent metabolic requirement has also been related to the differential habitat use in ungulates (McNab, 1963). Amongst sympatric ungulates, habitat selection was found to be dependent on the specific requirements and species specialization (Cairns & Telfer, 1980, Ben-Shahar, 1990).

It is generally assumed that animals will select a habitat that will be best able to satisfy its requirements and thus high quality resources will be selected more than low quality resources. But since availability is not uniform, use may change accordingly. Animal make decisions about where, when and what to eat (Bunnell & Gillingham, 1985) and optimality approaches have been used to examine outcomes (e.g. Krebs, 1978; Belovsky, 1981; Emlen, 1984). An implicit assumption of any foraging model or simpler food and habitat selection indices is that animal ‘knows’ what foods are available (Gillingham & Bunnell, 1989).

Sympatric ungulates tend to use their environment in different ways, which are determined by factors such as sex, body size, reproductive stage,

gut morphology and function and a variety of others (Hofmann & Stewart, 1972; Jarman 1974; Haneley, 1982; Demment & VanSoest, 1985; Gordon, 1989), resulting in niche differentiation or resource partitioning. Differential resource selection is one of the principle factors, which permit species to coexist. Many studies have also been conducted on ungulate habitat use and it's relation to sympatric ungulates to understand the mechanism that defines their differential habitat selection (Shannon *et al*. 1975; Cairns & Telfer, 1980; Putman, 1986; Carson & Peek, 1987; Ben-Shahar & Skinner, 1988, Ben-Shahar, 1990; Tufto *et al*. 1996; Latham *et al*. 1997; Doergeloh, 1998).

In theory, several potential mechanisms enable the coexistence of a group of species with similar ecologies (Putman, 1994; 1996). However, there is a popular belief that sympatric livestock competes with the wild ungulates due to their common range use (Sankar, 1994, Bagchi, 2001). Such descriptions are of course crude and over simplistic. Detailed study on the patterns of use of different habitat types for various activities of chital and sympatric livestock was conducted for different seasons over two consecutive years in the eastern sanctuary of Gir Protected area.

4.2 Methods

A group of chital was followed throughout the day from commencement of diurnal activity till night fall on 7-8 consecutive days in each season. Livestock herds were accompanied from their corral, where they were kept for the night, till they were brought back in the evening after completing the diurnal foraging circuit. The movements of both the groups were recorded with the help of hand held Global Positioning System (GPS) unit to compute the grazing circuit. Each location on movement path was recorded. The minimum distance between adjacent locations was 25- 30 m. Others details such as herd size, vegetation and habitat attributes, microhabitat and terrain were also noted for habitat use analysis. Grazing paths and circuits were computed and mapped on a classified LISS III satellite imagery.

Availability of different habitat types to chital and livestock were computed by plotting their grazing routs on the GIS map. A minimum convex polygon was generated using Arc GIS 9.2 software program (2006), to obtain

the area being used by chital and livestock in the intensive study area. Percentage coverage of each habitat type in the intensive study area was computed for the habitat availability.

Habitat use for various activity patterns was recorded during continuous scan monitoring of both the groups from early morning to late evening. To understand and justify the habitat use and preference of chital and livestock during different seasons for various activities, habitat selection index (Ivlev's electivity index) was computed (Ivlev, 1961). This index of selection is simple and easy to interpret and still widely used in practice (Krebs, 1989). The terms, preference and avoidance used here to explain the habitat selectivity are relative. Habitat showing negative preference or avoidance may be crucial under some circumstances (Bhatnagar, 1997) and ecological interpretation needs to be done with caution.

4.3 Results

4.3.1 Habitat Availability

The maximum foraging area of livestock of four *Maldhari Nesses* was 42.09 km^2. This area comprised of *Anogeissus* mixed forest (21.5 km^2), *Acacia Ziziphus* scrubland (9.5 km^2), *Boswelia Lanea Terminalia* vegetation on grassy hill tops (5.6 km^2), and moist mixed riverine vegetation (5.5 km^2). In case of the intensively observed chital herd, the foraging area was 2.23 km^2 which was composed of *Acacia Ziziphus* scrubland (0.92 km^2), *Anogeissus* mixed forest (0.81 km^2), moist mixed vegetations along the streamlines (0.48 km^2) and *Boswelia Lanea Terminalia* (0.021 km^2) vegetation.

4.3.2 Seasonal habitat use and selection by chital

Acacia- Ziziphus scrubland was the widely used habitat for various activities during all seasons. Chital were observed to be using *Acacia-Ziziphus* scrubland habitat significantly more than *Anogeissus* mixed vegetation and Moist mixed riverine vegetation for 'moving', 'resting', 'ruminating', 'foraging', 'vigilance' as well as 'other' activities throughout the year (One way ANOVA: Moving, $F= 94.76$, $p \leq 0.001$; Resting, $F=17.83$, $p \leq$

0.001; Ruminating, F=12.78, p ≤ 0.001; Foraging, F= 130.72, p ≤ 0.001; Vigilance, F= 53,18, p ≤ 0.001; Others, 69.01, p ≤ 0.001).

Anogeissus mixed vegetation type was the least used habitat for all observed activities compared to *Acacia Ziziphus* scrubland and moist mixed riverine habitat. The difference in habitat use for various activities between *Anogeissus* mixed vegetation and Moist mixed riverine vegetation was significant only for 'ruminating' as chital used riverine habitat significantly more than *Anogeissus* mixed vegetation for ruminating (*Tukey HSD post hoc* test, p ≤ 0.05).

4.3.2.1 Winter

During winter, the habitat use of chital for various activities was significantly different for different habitat types (One way ANOVA: Moving, F= 28.13, p ≤ 0.001; Resting, F= 5.57, p ≤ 0.05; Ruminating, F= 4.79, p ≤ 0.05; Foraging, F= 51.84, p ≤ 0.001; Vigilance, F= 32.69, p ≤ 0.001; Others, 32.11, p ≤ 0.001). *Acacia Ziziphus* scrubland was used significantly more than the other two habitats for various activities (*Tukey HSD Post hoc test*, p ≤ 0.05) (Figure- 4.1). The *Anogeissus* mixed vegetation was the least used habitat, contributing less than 20 % use in any of the activities during winter. Whereas the use of moist mixed riverine habitat was comparatively more for resting (34.0 ± 6.9 %) and ruminating (36.6 ± 7.8).

During winter, *Acacia Ziziphus* scrubland was the most preferred habitat of chital for all activities. Whereas *Anogeissus* mixed habitat was the least preferred or might have been avoided during this period. The moist mixed vegetation was the most preferred habitat for resting and ruminating activities. The movement coupled with foraging was preferably done in *Acacia Ziziphus* scrubland and relatively avoided in *Anogeissus* mixed vegetation and moist mixed riverine habitats. Chital spent more time in vigilance than expected in *Acacia Ziziphus* and riverine vegetation compared to *Anogeissus* mixed forest. *Acacia Ziziphus* was a preferred habitat for 'other' activities which included social interactions and unclassified activities. However, riverine vegetation was used in proportion to it's availability for other activities during winter (Figure- 4.1).

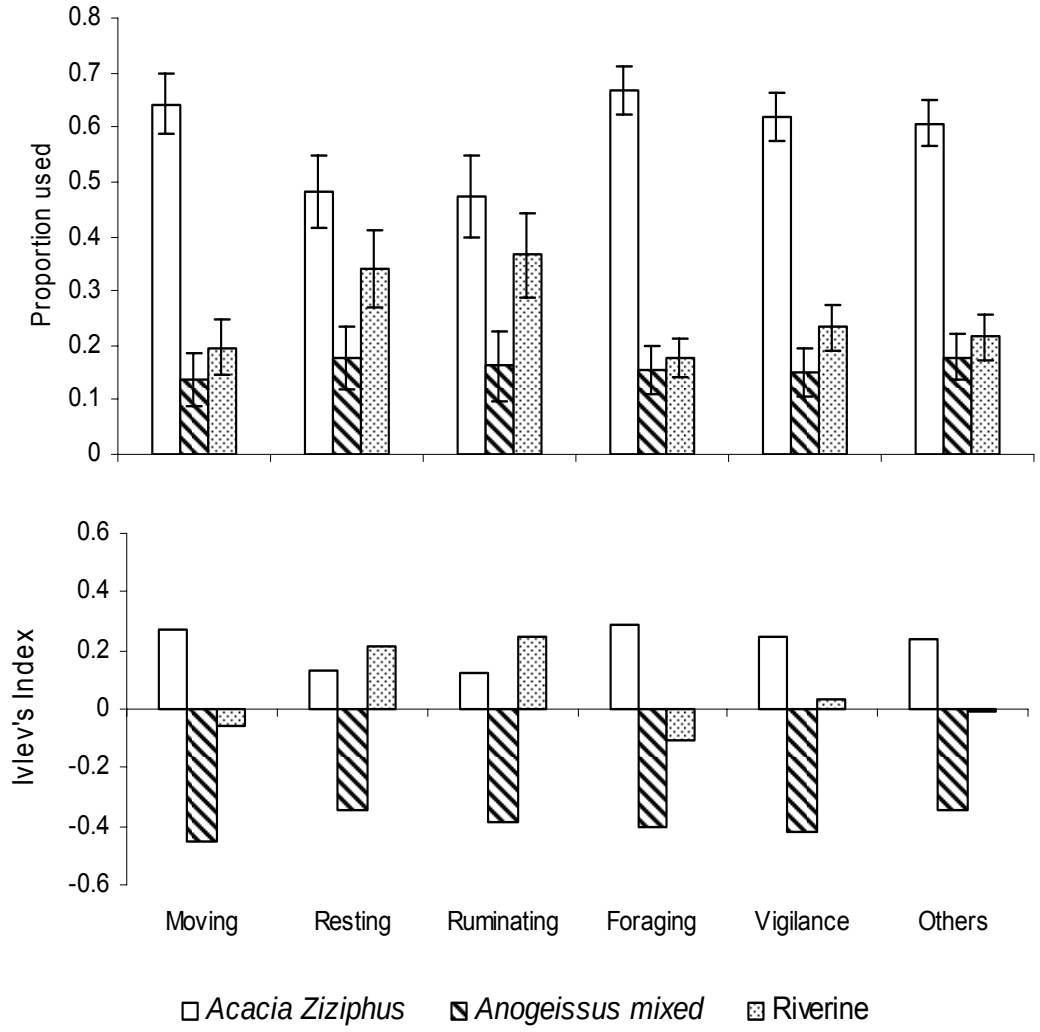


Figure- 4.1: Habitat use and preference for various activities by chital during winter in Eastern Gir Sanctuary. Error bars are standard errors.

4.3.2.2 Summer

During summer, the habitat use of chital for all the activities, except resting (One Way ANOVA: F= 2.77, p = 0.07) and ruminating (One Way ANOVA: F= 2.51, p = 0.09), was significantly different for different habitat types (One Way ANOVA: Moving, F= 28.33, p ≤ 0.001; Foraging, F= 36.48, p ≤ 0.001; Vigilance, F= 5.62, p ≤ 0.01; others, 11.17, p ≤ 0.001). Compared to winter, the contribution of *Anogeissus* mixed and riverine vegetation to the habitat use of chital during summer was more, especially for resting and ruminating (Figure-4.2). Most of the foraging activity was observed in the *Acacia Ziziphus* scrubland and was significantly higher than the other two

habitats i.e. Anogeissus mixed and riverine vegetation (*Tukey HSD Post hoc test*, $p \leq 0.001$). Resting and ruminating were observed mostly in the moist mixed riverine vegetation, although the other two habitats were not significantly different from riverine habitat (*Tukey HSD Post hoc test*, $p \geq 0.05$) in their use for ruminating and resting.

The *Anogeissus* mixed habitat is not preferred for any of the activities during summer (Figure -4.2). Foraging and foraging related movements were seen mostly in *Acacia Ziziphus* scrubland and chital showed clear selection for *Acacia - Ziziphus* scrubland for these activities along with other activities. Compared to winter, the selection for resting and ruminating was altered as riverine habitat was preferred for these activities. Hence, vigilance which was seen closely related to resting and ruminating activities too increased proportionately in riverine habitat.

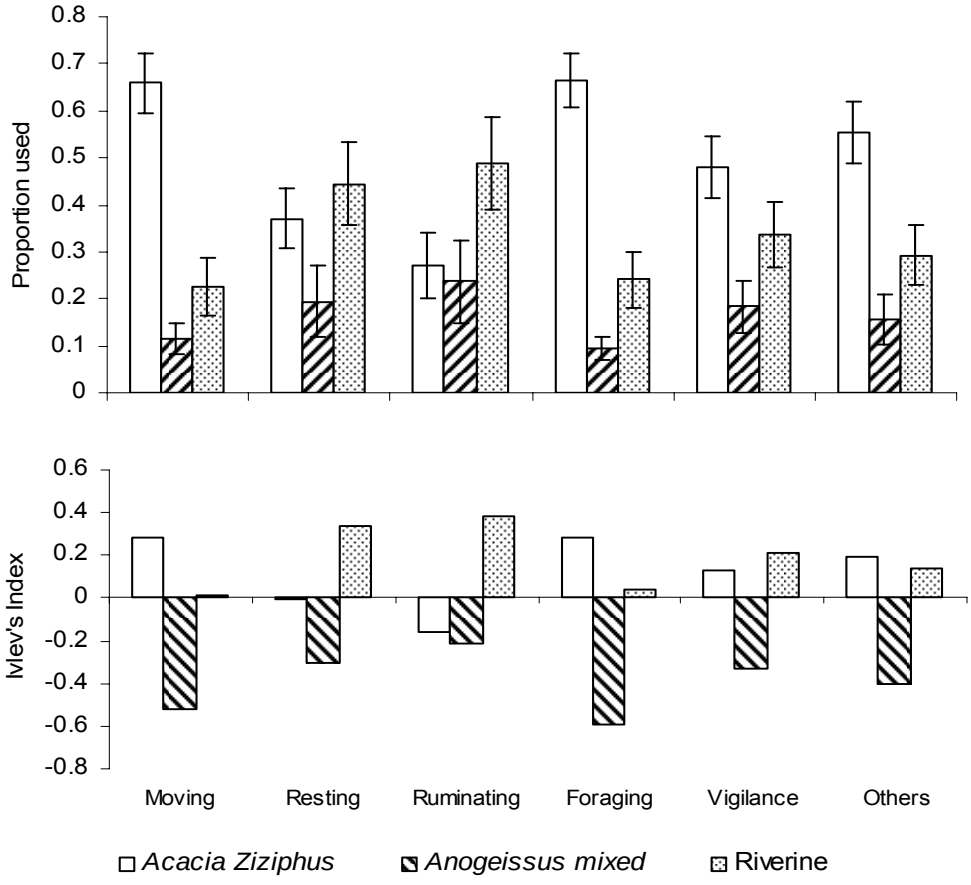


Figure- 4.2: Habitat use and preference for various activities by chital during summer in Eastern Gir Sanctuary. Error bars are standard errors.

4.3.2.3 Monsoon

During monsoon, *Acacia Ziziphus* scrubland was overwhelmingly used for all the activities. Hence, the habitat use for all activities was significantly different for habitat types (One way ANOVA: Moving, $F= 59.20$, $p \leq 0.001$; Resting, $F=58.87$, $p \leq 0.001$; Ruminating, $F=75.36$, $p \leq 0.001$; Foraging, $F= 48.74$, $p \leq 0.001$; Vigilance, $F= 35.42$, $p \leq 0.001$; Others, 41.10, $p \leq 0.001$). The use of *Acacia Ziziphus* scrubland was more than 70 % for all the observed activities during this season (Figure – 4.3). The pattern of use of different habitat during wet season i.e. monsoon was quite different from dry seasons i.e. winter and summer. During wet season i.e. monsoon chital used open habitats with little canopy cover i.e. *Acacia Ziziphus* scrubland and *Anogeissus* mixed habitats for all diurnal activities and seldom used moist mixed riverine forest with closed canopy.

During monsoon, chital showed a clear selection for the *Acacia Ziziphus* scrubland habitat (Figure – 4.3), while the least preferred habitat for all the observed activities, except ruminating, was moist mixed riverine habitat. *Anogeissus* mixed vegetation was ranked second in its' use by chital in monsoon.

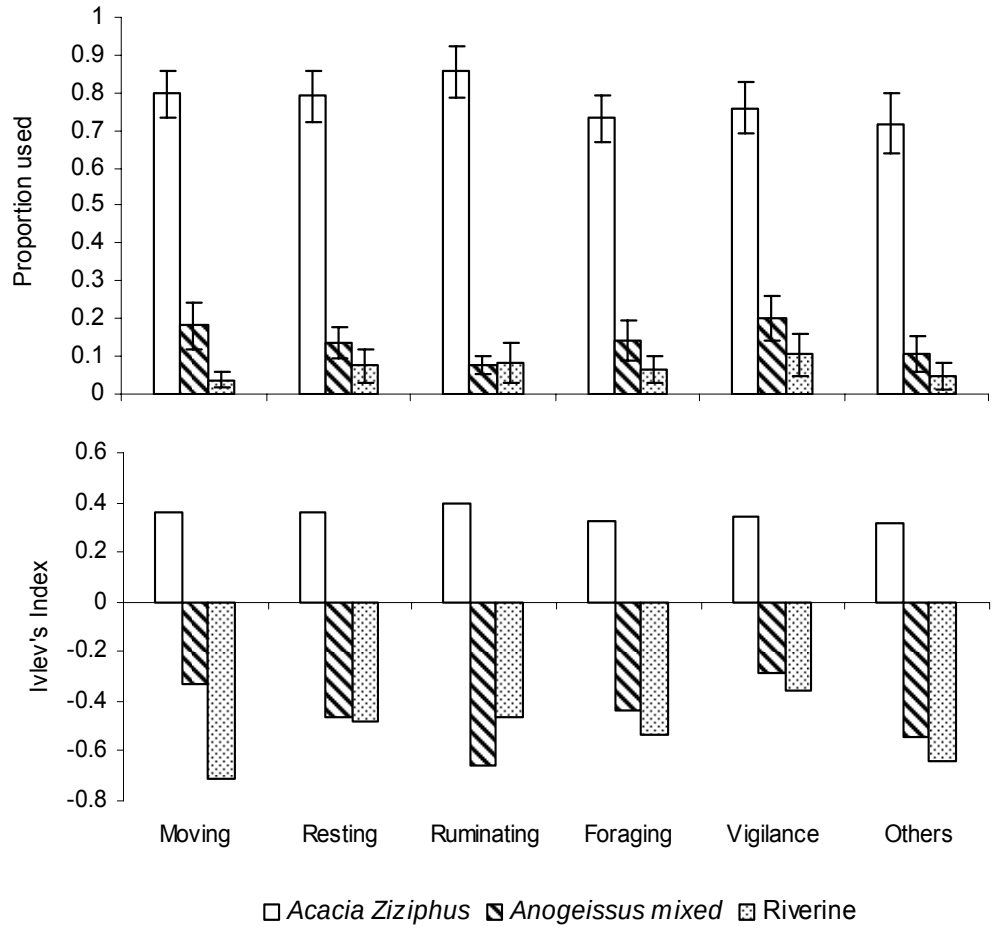


Figure- 4.3: Habitat use and preference for various activities by chital during monsoon in Eastern Gir Sanctuary. Error bars are standard errors.

4.3.3 Seasonal Habitat use and selection by cattle and buffalo

Livestock i.e. cattle and buffalos were herded as a mixed herd in early morning from the *Ness* to forage and were accompanied by herders. The foraging habitat choice was partly determined by accompanying herdsmen. Livestock i.e. cattle and buffalo were observed using different habitat differently for various activities. Several activities like resting and ruminating were more or less restricted to the moist mixed riverine vegetation during all seasons. The fourth habitat i.e. *Boswelia Lanea Terminalia* which was not used by chital habitat was found to be used by livestock for their various activities (Figure- 4.4). The overall habitat use of buffalo was different for various activities (One way ANOVA: Moving, $F= 16.01$, $p \leq 0.001$; Resting, $F= 122.32$, $p \leq 0.001$; Ruminating, $F= 130.36$, $p \leq 0.001$; Foraging, $F= 37.80$, $p \leq$

0.001; Others, 4.60, p ≤ 0.01) except vigilance (One way ANOVA, F = 1.19, p ≤ 0.314). Whereas, overall cattle habitat use was different for all activities (One way ANOVA: Moving, F= 22.58, p ≤ 0.001; Resting, F= 86.56, p ≤ 0.001; Ruminating, F= 92.39, p ≤ 0.001; Foraging, F= 20.65, p ≤ 0.001; Vigilance, F = 2.68, p ≤ 0.05; Others, 4.60, p ≤ 0.01).

4.3.3.1 Winter

Habitat use of buffalo and cattle were very similar during winter (Figure- 4.4 & 4.5). The proportionate time spent in different habitat types for all observed activities was different for cattle (One way ANOVA: Moving, F= 13.39 p ≤ 0.001; Resting, F= 51.81 p ≤ 0.001; Ruminating, F= 58.0, p ≤ 0.001; Foraging, F= 20.78 p ≤ 0.001; Vigilance, F = 3.88, p ≤ 0.01; Others, F= 5.99, p ≤ 0.01) as well as for buffalos (One way ANOVA: Moving, F= 13.96 p ≤ 0.001; Resting, F= 72.37 p ≤ 0.001; Ruminating, F= 83.05, p ≤ 0.001; Foraging, F= 21.89 p ≤ 0.001; Others, F= 3.79, p ≤ 0.01) except vigilance (One way ANOVA: F = 1.66, p = 0.178).

Acacia Ziziphus scrubland was used more for moving by buffalo and cattle, than other habitat types (*Tukey HSD Post hoc test*, p ≤ 0.05). Although the buffalo and cattle foraged more in *Anogeissus* mixed forest, than riverine and *Boswelia Lanea Terminalia* vegetation (*Tukey HSD Post hoc test*, p ≤ 0.05) it was not different from *Acacia Ziziphus* scrubland (*Tukey HSD Post hoc test*, p ≥ 0.05). The use of moist mixed riverine forest for resting and ruminating by livestock was more in comparison to other habitat types (*Tukey HSD Post hoc test*, p ≤ 0.05).

The habitat selection for various activities of cattle and buffalo was similar except for ‘vigilance’. The proportionate time spent on vigilance was more than expected in moist mixed habitat by buffalos and in *Acacia Ziziphus* scrubland by cattle.

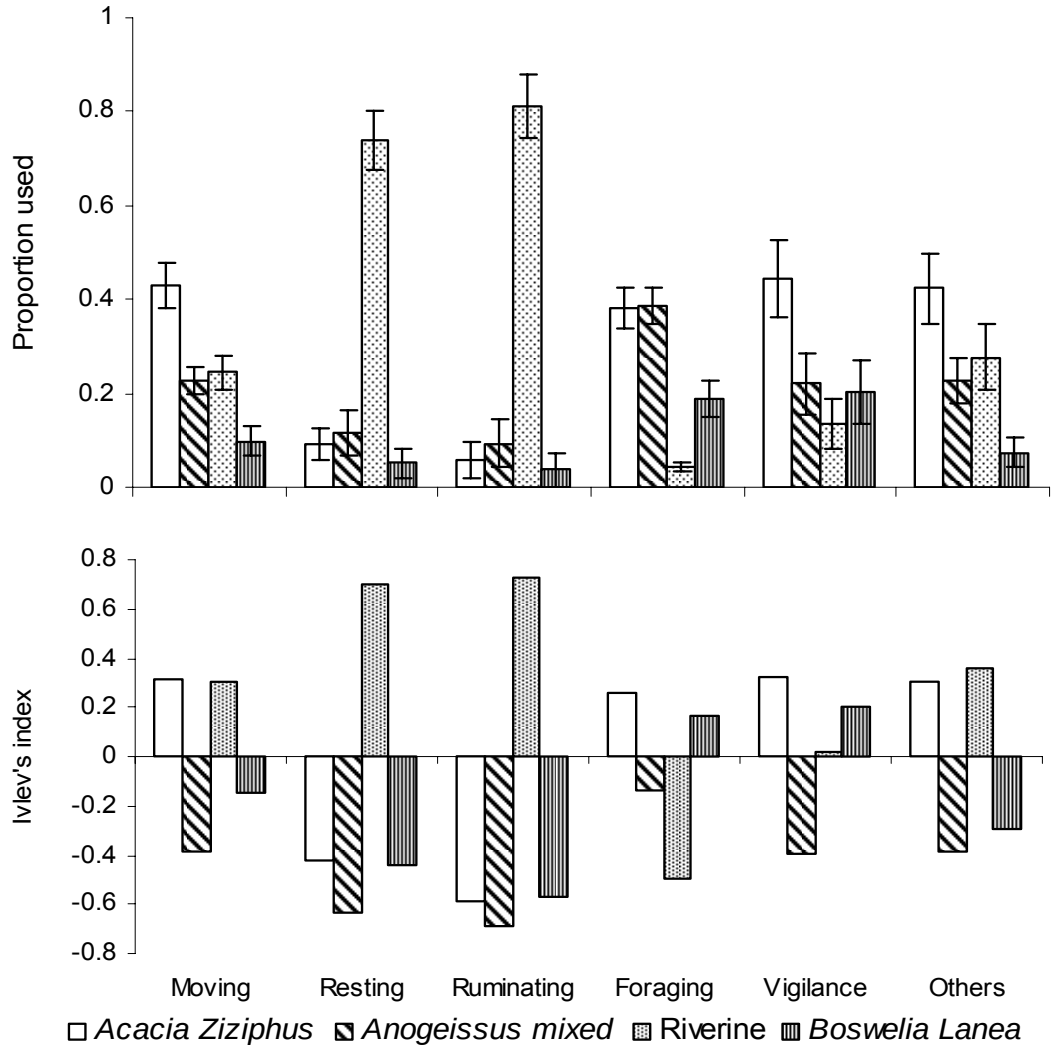


Figure- 4.4: Habitat use and preference for various activities by cattle during winter in Eastern Gir Sanctuary. Error bars are standard errors.

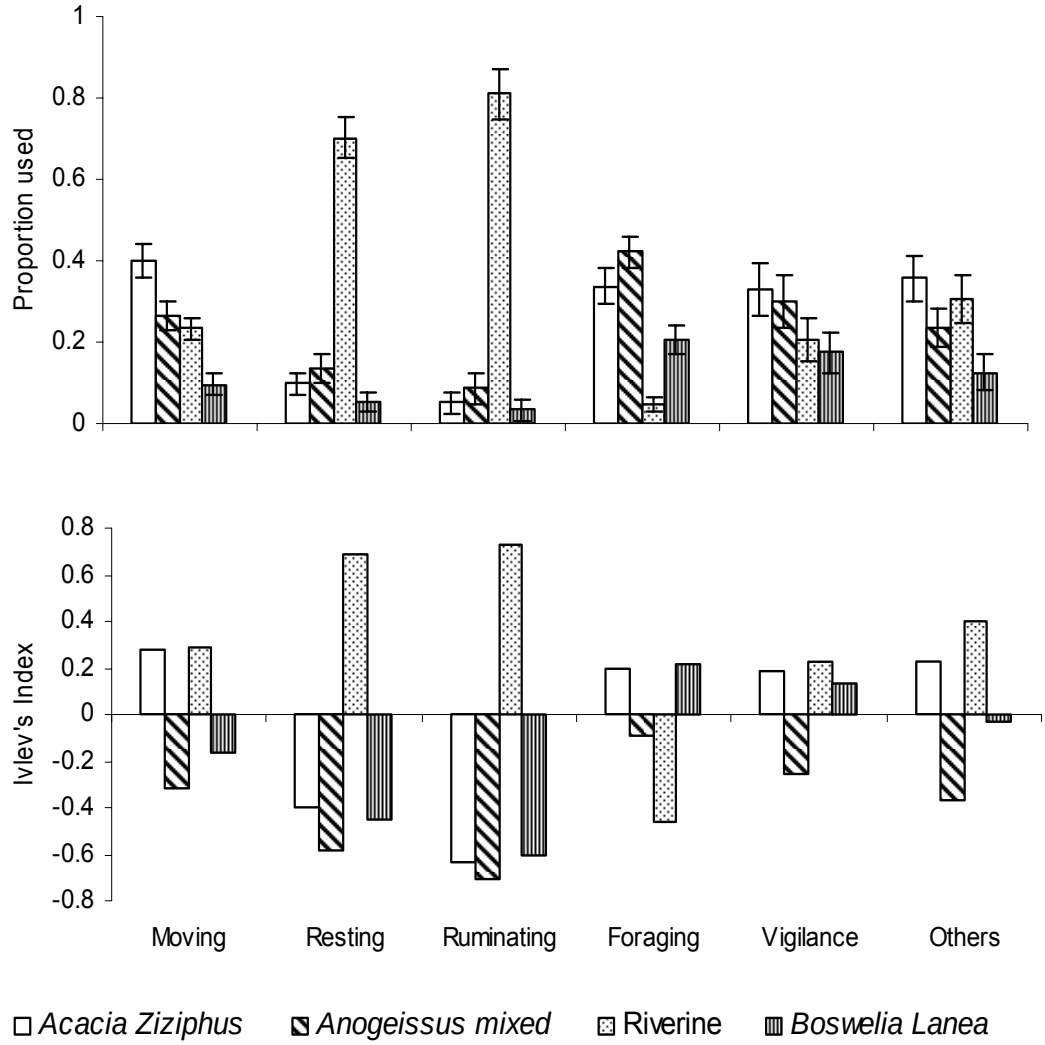


Figure- 4.5: Habitat use and preference for various activities by buffalo during winter in Eastern Gir Sanctuary. Error bars are standard errors.

4.3.3.2 Summer

During summer, the contribution of moist mixed riverine vegetation had increased and *Acacia - Ziziphus* scrubland decreased for various activities of cattle and buffalo. Habitat use of buffalo for all observed activities was different for various habitats (One way ANOVA: Moving, $F= 4.24$ $p \leq 0.01$; Resting, $F= 1682.84$ $p \leq 0.001$; Ruminating, $F= 4423.13$, $p \leq 0.001$; Foraging, $F= 11.16$ $p \leq 0.001$; Vigilance, $F = 4.48$, $p \leq 0.01$; Others, $F= 5.39$, $p \leq 0.01$). Although cattle habitat use for various activities was different for different habitat types (One way ANOVA: Moving, $F= 10.84$, $p \leq 0.001$; Resting, $F= 2193.72$, $p \leq 0.001$; Ruminating, $F= 8005.60$, $p \leq 0.001$; Vigilance, $F = 14.55$, $p \leq 0.001$; Others, $F= 6.19$, $p \leq 0.01$), habitat use for foraging was not significantly different (One way ANOVA, $F= 2.604$ $p = 0.06$). Compared to winter, ruminating in cattle and buffalo was restricted to the moist mixed riverine habitat during summer. The use of *Anogeissus* mixed vegetation for buffalo foraging, and moist mixed riverine habitat for other activities of cattle and buffalo had increased during summer (Figure- 4.6 & 4.7).

The selection for different habitats for various activities of cattle and buffalo were similar except foraging where moist mixed riverine vegetation was the most preferred habitat by cattle but at the same time it was the least preferred or avoided habitat for foraging by buffalos. Both, cattle and buffalo showed a selection for *Boswelia Lanea Terminalia* vegetation for foraging during summer.

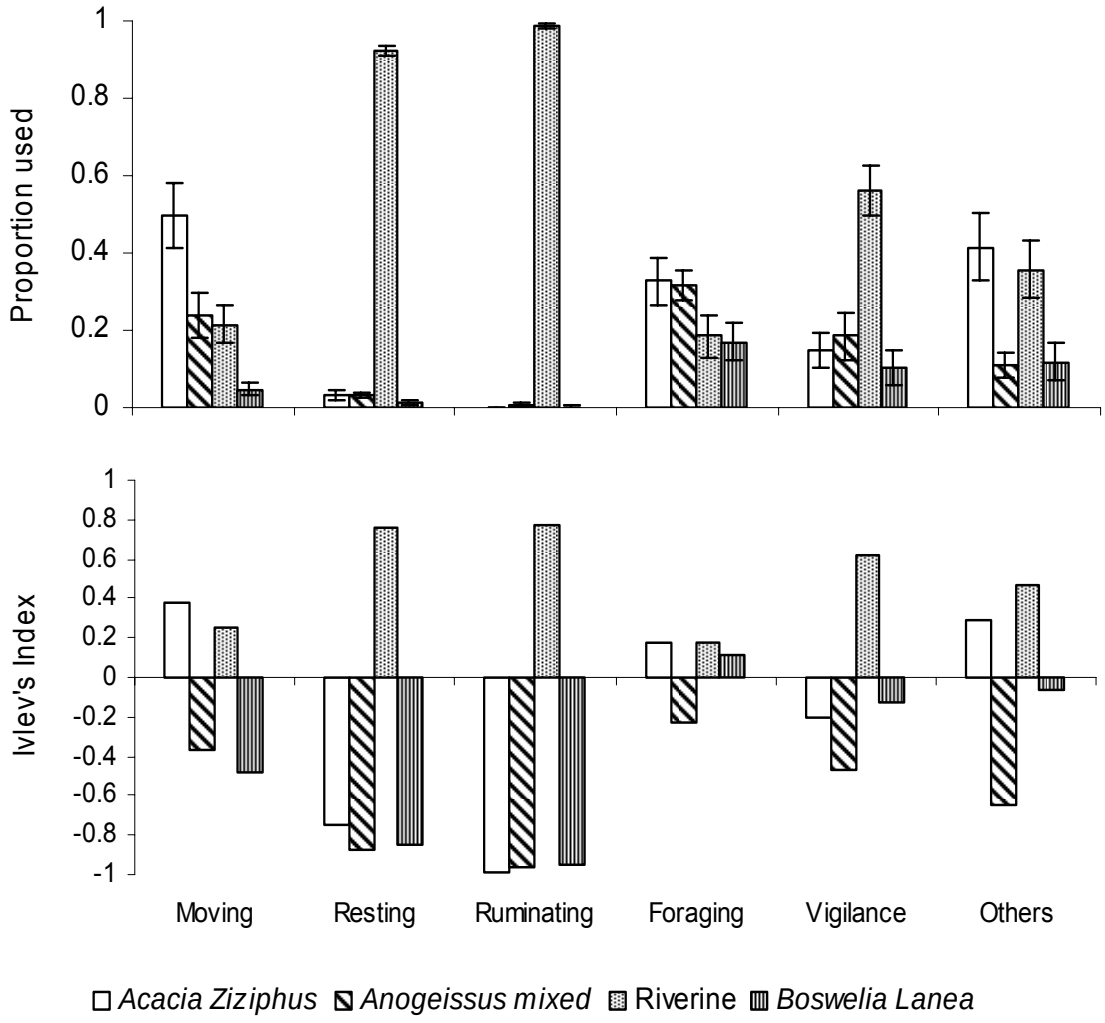


Figure- 4.6: Habitat use and preference for various activities by cattle during summer in Eastern Gir Sanctuary. Error bars are standard errors.

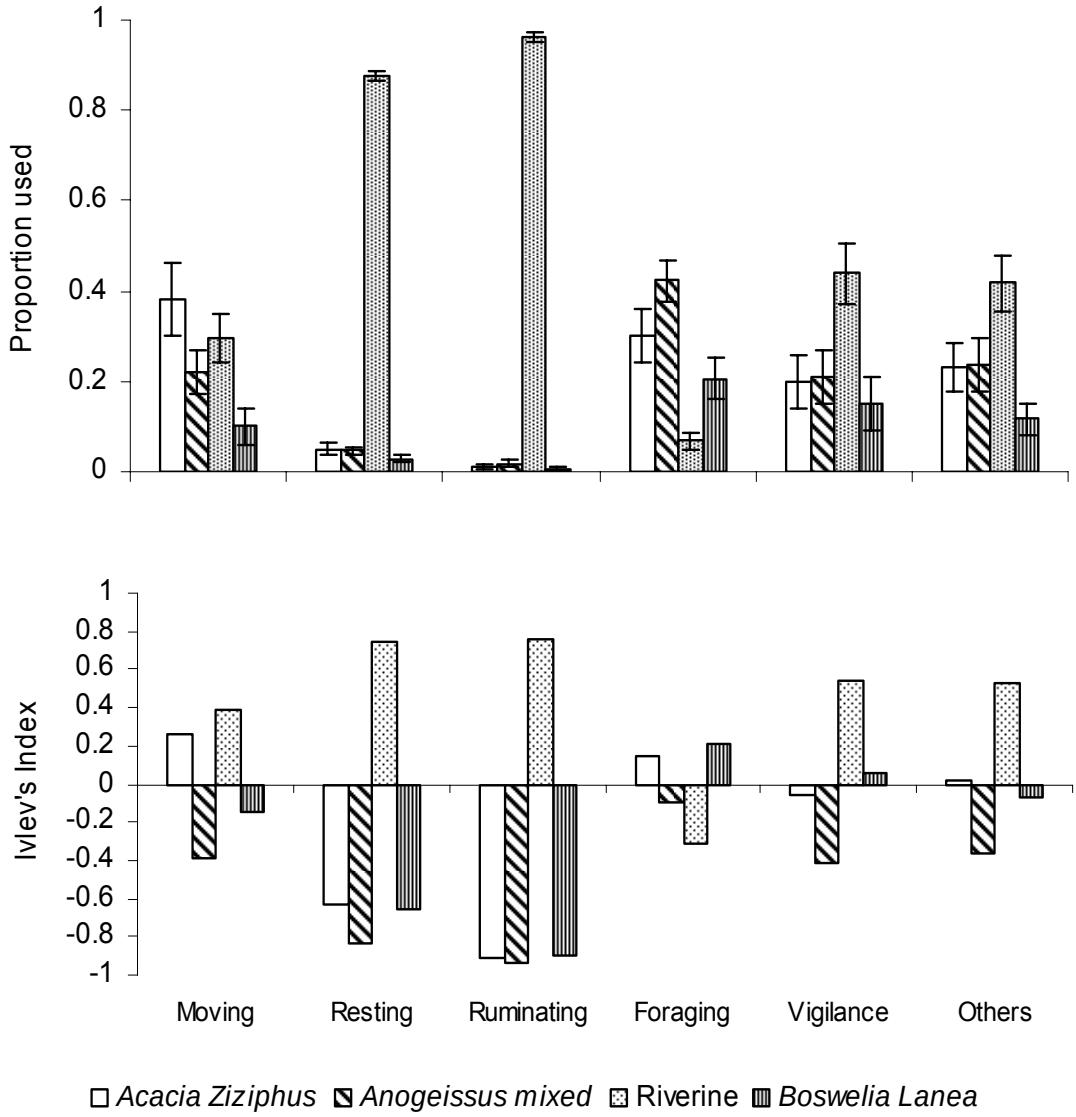


Figure- 4.7: Habitat use and preference for various activities by buffalo during summer in Eastern Gir Sanctuary. Error bars are standard errors.

4.3.3.3 Monsoon

During monsoon, the contribution of moist mixed riverine habitat to various activities of livestock had decreased due to cooler air temperature and improved water availability in other habitats. Cattle used all habitats indifferently for all activities except 'foraging' (One way ANOVA, $F = 14.32$, $p \leq 0.001$) and 'others' (One way ANOVA, $F = 3.69$, $p \leq 0.05$). Similarly, habitat use by buffalo was different for 'foraging' (One way ANOVA, $F = 15.81$, $p \leq 0.001$) and 'other' (One way ANOVA, $F = 8.61$, $p \leq 0.001$). The use of *Anogeissus* mixed vegetation for foraging by cattle and buffalo was more than other habitat types during this season (One way ANOVA: *Tukey HSD Post hoc test*, $p \leq 0.05$). The habitat use for 'resting' and 'ruminating' by both i.e. cattle and buffalo shifted from the moist mixed riverine vegetation to *Acacia Ziziphus* scrubland during monsoon. Besides, overall contribution of *Boswelia Lanea Terminalia* to the livestock habitat use for all observed activities had increased comparatively. The moist mixed vegetation in which livestock spent considerable amount of time on different activities during winter and summer was least used habitat during monsoon.

The habitat selection for different activities of livestock during wet season i.e. monsoon showed a marked change compared to previous dry seasons i.e. winter and summer. For 'resting' and 'ruminating', selection had changed from moist mixed to *Acacia Ziziphus* scrubland. The habitat use and selection for 'moving', 'foraging' and 'others' it shifted from moist mixed to *Boswelia- Lanea- Terminalia* vegetation.

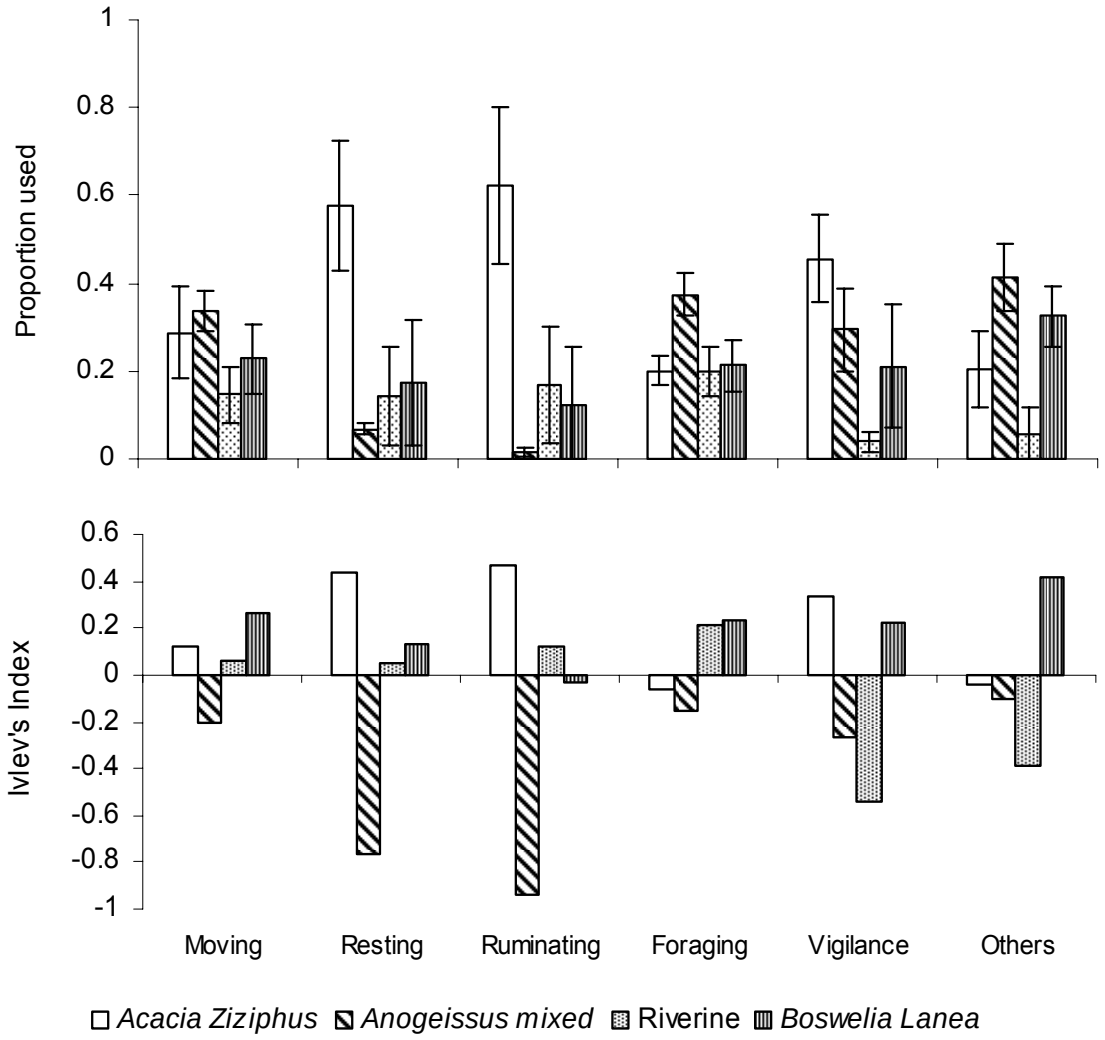


Figure- 4.8: Habitat use and preference for various activities by cattle during monsoon in Eastern Gir Sanctuary. Error bars are standard errors.

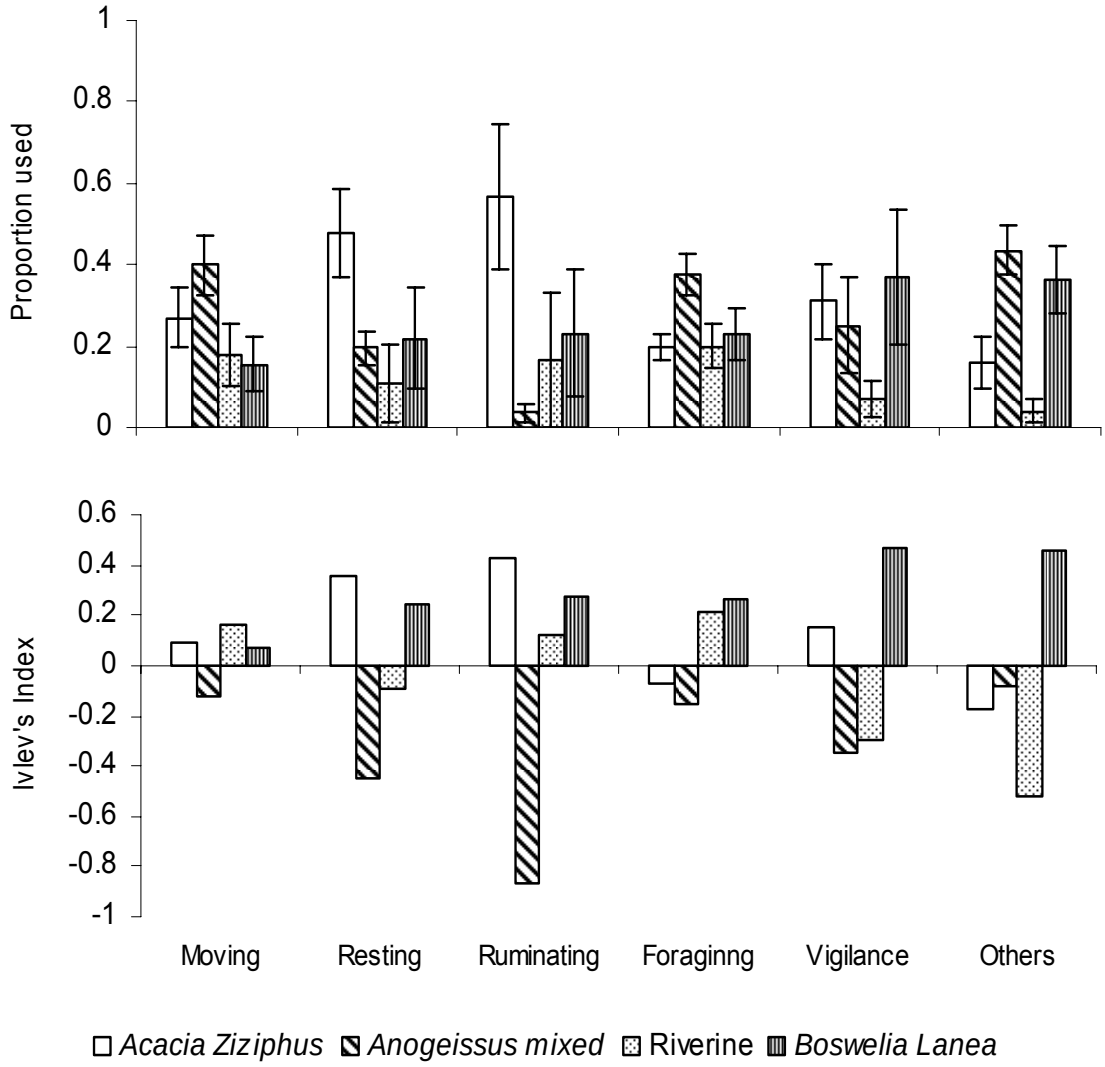


Figure- 4.9: Habitat use and preference for various activities by buffalo during monsoon in Eastern Gir Sanctuary. Error bars are standard errors.

4.4 Discussion

Chital has been considered as a generalist forest dwelling species occupying forest edges and ecotone zones between forest and grasslands (Berwick, 1974; Schaller, 1967; Eisenberg, 1981; Khan, 1993). During this study too, chital were observed using open scrubland with scattered shady trees and the edges of dense forest patches near water sources. Among four broad habitat types occurring within the intensive study area, chital was found active mostly in *Acacia- Ziziphus* scrubland which occurs generally in flat terrain habitat with the mosaic of open scrubland and dense bushy vegetation. In case of livestock, they used all four habitats in the study area and preferentially foraged in *Boswelia - Lanea - Terminalia* vegetation with abundant grasses and preferred moist mixed riverine vegetation for resting and ruminating during most part of the year.

4.4.1 Habitat segregation between chital and livestock for different activities

Acacia Ziziphus scrubland was predominantly used by chital and livestock for foraging in all seasons. Chital being species of forest edges and open habitat, showed a clear preference for *Acacia - Ziziphus* scrubland throughout the year for various diurnal activities, as it provides good foraging opportunity to chital. However, this habitat was not a preferred habitat for foraging by cattle and buffalo during most part of the year.

The moist mixed riverine habitat contributed little to the chital and livestock foraging as the preference for foraging was relatively low for this habitat during all three seasons. Nevertheless, the moist mixed riverine vegetation was highly preferred habitat for resting and ruminating by chital as well as livestock. Such dense bushy vegetation provides shelter and protection from hot summer afternoons and cold windy days of winter (Fusch, 1977).

The foraging by chital in *Anogeissus* mixed vegetation seems rather constrained by environmental factors like cover (Putman, 1988) and water availability (Schaller, 1967) than forage availability. The *Anogeissus* mixed vegetation is largely composed of dry deciduous trees and hence it does not

provide shelter or cover during dry and hot part of the year. Therefore, chital tended to avoid this habitat for foraging. Although the water availability was poor in *Anogeissus* mixed vegetation, the forage in terms of grass, fallen leaves and fruits as well as browse within the reach of wild and domestic herbivores remains available (though not abundant) almost round the year. In case of livestock, *Anogeissus* mixed vegetation constitutes a major portion of their foraging area, although it was not a preferred habitat for foraging of livestock.

Boswelia – Lanea - Terminalia habitat contributed significantly to livestock activity during all seasons but chital did not use this habitat throughout the sampling period. Though *Boswelia Lanea Terminalia* habitat was not a preferred habitat for livestock, it played a vital role in the habitat separation between chital and livestock.

4.4.2 Seasonal trends in habitat use and selection by chital and livestock

Seasonal variation in the habitat use was observed for different activities especially for foraging by both i.e. chital and livestock. During all three seasons, foraging by chital was largely restricted to *Acacia Ziziphus* scrubland (Figure 4.1, 4.2 & 4.3). Therefore, habitat preference during dry seasons i.e. summer and winter, for foraging by chital was clearly for *Acacia Ziziphus* scrubland as fruits and pods of *Ziziphus sp.* and *Acacia sp.* remain available in this habitat, while during monsoon, *Acacia Ziziphus* scrubland habitat offers patchily distributed short grasses and forbs. Habitat use and preference of chital during wet season i.e. monsoon was quite different from dry seasons i.e. winter and summer (Figure- 4.1, 4.2 & 4.3). The seasonal trend in the pattern of habitat use and preference of chital revealed that habitat use and preference was not largely affected by broad habitat structure or other extraneous biotic factors, but seems rather influenced by microclimatic conditions defined by several abiotic factors like ambient temperature, humidity and water availability. Thus, *Acacia - Ziziphus* habitat was most used for foraging by chital while, *Anogeissus* mixed and *Acacia - Ziziphus* habitats were used most for foraging by livestock. However, the habitat preferences for foraging were different between chital and livestock as

chital preferred *Acacia Ziziphus* scrubland while the most preferred foraging habitat of livestock was *Boswelia Lanea Terminalia*, during all three seasons.

The herders were seen facilitating livestock by availing pods, fruits and green leaves by lopping. Therefore this scrubland and thorn forest habitat, otherwise not lucrative for livestock was observed contributing to livestock foraging by human facilitation. Hence livestock preference for this habitat could not be viewed as a natural preference by livestock. During resource crunch period i.e. summer, livestock had no clear preference for foraging and therefore foraging was more or less diffused across habitats. During this dry and hot season, livestock movement was restricted by high ambient temperature and scarce water availability. Most of the livestock were stall fed on grass and occasional browse after their daily foraging activity. Besides, productive livestock were fed on nutritious supplement cattle feed throughout the year and during resource crunch period unproductive and weaker livestock were also fed on supplementary cattle feed. The diet supplementation could have played a key role in segregating the functional niches of chital and livestock during resource poor period of the year which is the potential period for resource competition.

The difference in cattle and buffalo foraging was observed for the riverine habitat during summer. The riverine habitat was mostly used by livestock to retire after the morning foraging session, where buffalos spent prolonged time wallowing, resting and ruminating while many of the cattle kept foraging in the vicinity. Although this habitat is extremely limited in size, restricted as linear strips along water course, it is highly preferred habitat as these stretches provide good variety of food items. The probability of encountering large carnivores is relatively higher in dense riverine patches as well as difficult for *Maldharis* to keep a close watch on entire herd. Hence, herd keepers don't allow their livestock to forage in this habitat for longer durations.

4.4.3 Theoretical explanation for the differential habitat selection by chital and livestock

The differences in habitat selection for foraging between chital and livestock actually reflect the difference in their body size, mouthparts, morphology and ecological adaptations evolved over a evolutionary time scale. However, the role of the short term response of either of the species to their sympatric counterparts can not be overruled.

The foraging opportunity for one species (in this case chital) in a particular habitat, may not be rewarding for other species (in this case, livestock). Therefore, not the broad habitat structure but the microhabitat variables like distribution, abundance and size of the food items in that habitat as well as other abiotic features which possibly drives the intensity of it's use by different herbivores (Bowyer *et al*. 1999). However, it was not possible to incorporate such 'foraging opportunity' available in particular habitat for chital or livestock. For a generalist feeder like chital which readily switches over from grazing to browsing and vice-versa (Schaller, 1967; Tak & Lamba, 1984; Dinerstein, 1987 & 1989), foraging resources are located in a three dimensional space. Therefore foraging opportunity for chital increases in a given area compared to livestock. The livestock i.e. cattle and buffalo largely depend on the forage available on the forest floor. For e.g., during monsoon, when large portion of the forest floor remains water logged for a long period and ground cover comprises of scattered browse items as well as short annual grasses and forbs, livestock switched their preference to *Boswelia Lanea Terminalia* vegetation located on open, grassy hill slopes with ample grass resources, whereas chital, still preferred *Acacia Ziziphus* scrubland due to their ability to exploit the available food resources. The results of habitat use for foraging is strongly supported by food habit study, as major food items of chital diet in monsoon were browse rather than graze (Chapter- 5).

A model developed by Illius & Gordon (1987), based on the allometry of metabolic requirements and bite size, is used to provide a mechanistic explanation for the observation that chital were able to exploit highly nutritious food items during winter, whereas the livestock moved off to feed on poorer quality but abundant food at this time. During winter, fruits of the *Ziziphus mauritiana* and pods of *Acacia nilotica, Acacia leucophloea, and Acacia*

catechu along with tender leaves of *Acacia sps* and *Ziziphus mauritiana* were available in *Acacia Ziziphus* scrubland. However, tiny but highly energetic fruits, pods and leaves protected by sharp thorns, were practically unavailable to the livestock due to the differences in the size and shape of the mouthparts of a chital *vis-a-vis* cattle-buffalo (Illius & Gordon, 1990). In addition to the mouthpart differences, larger body size and bigger gut capacity of cattle and buffalo do not allow them to spend energy on searching food in a habitat with scattered food as well as on the food items which were quite smaller than their usual bite size (Kleiber, 1961; Bell, 1971; Hofmann & Stewart, 1972). Nonetheless such food items were high in the crude protein content (Chapter 5). It has also been pointed out that for plant foods; quality and abundance are often inversely correlated (Wilson, 1976; Gaulin, 1979). This has been generally true in this study as well. Therefore, livestock preferred *Boswelia Lanea Terminalia* vegetation with vast open grassy patches which offers forage in bulk i.e. tall perennial grass species (Hofmann, 1973). The difference in their habitat selection could be attributed to their foraging strategy by which they maximize on energy in terms of forage intake. In a broader sense, it can be inferred that livestock look for 'quantity' and chital look for 'quality' during their food search. Thus, livestock and chital both keyed in on similar habitats to obtain their food.

The habitat utilization and selection by chital and sympatric livestock were observed to be somewhat different. Putman (1996) stated that 'even extensive overlap in patterns of habitat use (earlier chapter) is immaterial in that the habitat is not 'consumed'; overlap becomes significant only where patterns of overlap in habitat combines with the patterns of overlap in use of a genuine depletable resources, such as food'. Hence before concluding anything based on habitat use and selection patterns, detailed food habits of chital as well as cattle and buffalo is essential.

CHAPTER 5

Food habits of Chital, cattle and buffalo

5.1 Introduction

Relations between animal populations and their food supplies form a central theme both in theoretical ecology as well as for the management of natural and man-modified ecosystems (Owen Smith & Novellie, 1982). Understanding food habits is an essential component of research efforts addressing issues related to ecology of the species of interest and their interface with sympatric animals and immediate environment.

There is no dearth of the information on the food habits of wild herbivores in Africa (Talbot & Talbot, 1962; Gwynne & Bell, 1968; Leuthold, 1977; Bell, 1971; Jarman & Sinclair, 1979), in North America (Tueller, 1979; Spowart & Hobbs, 1985; Stephenson *et al*. 1985; Spallinger & Hobbs, 1992) and Europe (Jackson, 1974; Putman *et al*, 1993; Mann, 1983; Mann & Putman, 1989). In most wildlife sanctuaries and National Parks of India, domestic livestock graze legally or illegally alongside with wild ruminants and remain associated with them. However, except for a few attempts, very little has been known on the food habits of wild ungulates especially chital, in India (Schaller, 1967; Green, 1985; Haque, 1990; Johnsingh & Shankar, 1991; Berwick, 1974; Khan, 1993).

Ruminant ungulates are classified according to their contrasting foraging strategies: 'grazers' are bulk roughage feeders eating mainly grasses; 'browsers' are concentrate selectors who selectively ingest forbs and parts of woody plants such as leaves, buds and twigs (Hofmann & Stewart, 1972). Rodgers (1988) has categorized chital as a generalist ruminant. Whereas, livestock i.e. cattle and buffalo are known generally as bulk feeders, consuming large quantities of forage of low to medium quality. They preferentially graze in grass-dominated vegetation types (Duncan, 1983; Pratt *et al*. 1986; Putman *et al*. 1987; Gordon, 1989; Menard *et al*. 2002) and graminoids form the bulk of their diet (Van Dyne *et al*. 1980).

The most well debated issues in theoretical ecology as well as practical wildlife management are interspecific interactions such as food competition and resource partitioning among sympatric ungulates (White, 1978; Caughley & Sinclair, 1994; Putman, 1996; Abrams, 1998; Murray & Illius, 2000; Arsenault & Owen-Smith, 2002). The understanding of resource use overlap in terms of habitat and diet is a useful approach to understanding such interactions (Schoener, 1974; Jones & Barmuta, 1998; Mysterud, 2000).

Dietary patterns can provide insight into potential for competition. However the relationship between dietary overlap and interspecific competition is not very clear (Abrams, 1980). Although, any differences in patterns of diet selection can reduce the chances of the potential competition between sympatric herbivores (Jarman & Sinclair 1979, Schwartz & Ellis 1981, Hobbs *et al*. 1983).

As a general understanding, high diet similarity between sympatric species indicates competitive interaction at high density and limited food resources. However, due to the difference in morphological (Gordon & Illius, 1988) and physiological (Hofmann, 1989) characteristics of sympatric species, they differ in their feeding styles (Hofmann & Stewart, 1972). Sometime due to the differences in their foraging styles, both of them or one of the species may also benefit from coexistence through feeding and/or habitat facilitation (Vesey-Fitzgerald, 1960; Bell, 1971; McNaughton, 1976, 1979; Prins & Olff 1998; Arsenault & Owen-Smith, 2002).

Several studies have explained the mechanism of niche differentiation among sympatric herbivores, which to a large extent is related to differences in body size (Bell, 1971; Jarman, 1974; Demment & Van Soest, 1985). Smaller ungulates are more selective in the makeup of their dietary composition than larger species (Bell, 1971; Jarman, 1974; Gordon & Illius, 1996), whereas large-bodied ungulates have less time to be selective. This is because they require more food, and hence they ingest larger quantities of lower quality forage (Owen-Smith, 1988). As it is evident from previous studies (Demment & Van Soest, 1985; Illius & Gordon, 1987), smaller animals have relatively greater energy requirements than larger animals. Small animals tend to select more for ‘quality’, while larger animals may be less selective and search for ‘quantity’. In addition, larger herbivores have larger mouth parts and are therefore unable to forage with a high degree of selectivity compared to smaller herbivores (Illius & Gordon, 1990)

Many studies have been carried out in temperate and Afro-tropical large mammal assemblages on food interactions among sympatric ungulates (Vesey-Fitzgerald, 1960; Gwynne & Bell, 1968; Bell, 1970; McNaughton, 1979; Jarman & Sinclair, 1979; Jenkins & Wright, 1988; Gordon & Illius, 1989; Putman, 1996; Voeten & Prins, 1999; Mysterud, 2000; Woolnough & du Toit,

2001; Stewart *et al*. 2003; Gayot *et al*. 2004). However, very little information is available on the diets of wild ungulates and sympatric livestock in the Indian context (but see, Schaller, 1967; Berwick, 1974; Johnsingh & Sankar, 1991).

As a close approach to understand the complex interactions between chital, a wild ruminant and sympatric domestic ruminants i.e. cattle and buffalo at a site specific scale, the detailed food habits of these three sympatric ungulates were studied seasonally for six consecutive seasons i.e. two years. Major food items were analyzed for their chemical composition to understand the role of nutritional value of different food items in the diet selection by these ungulates.

5.2 Methods

Laboratory and field research designed to advance our understanding of food preferences and availability, nutritive values of natural food items and the nutritive requirements of an animal is essential to scientific wildlife management (Thompson *et al*. 1973). The food habit study was carried out by direct observations. Direct observation has been widely used for estimating food habits of large herbivores (Wallmo & Neff, 1970; Jhala, 1997). Individual free ranging animals were selected and watched through binoculars or a spotting scope as they graze or browse and the type and the frequency of bites of plant parts and species consumed were recorded in different habitats in different seasons. Observations were quantified as bite counts (number of bites of a particular food item) (Berwick, 1974; Jhala, 1991 & 1997; Schaller, 1967). Approximately 1000 to 2000 bites were counted seasonally in each habitat types for each animal species i.e. chital, cattle and buffalo. Later, a fixed number of bites (25 & 40 bites for cattle & chital, respectively) were simulated by hand plucking the parts of major food plants eaten by chital, cattle and buffalo. The fresh weight of these simulated bites was taken immediately and then stored in paper bags for dry weight and chemical compositions. The simulated bites were dried at 57 ^{0}C in hot air oven before weighing for dry weight computation. This exercise was carried out for chital, buffalo and cattle in different habitat types known to be used by chital during different seasons through continuous scan sampling (Chapter -4).

The detailed food habits of all three herbivores were computed for different seasons. Habitats were rated according to the proportion of grazing activity of chital, cattle and buffalo in each of them as estimated from scan sampling (Jhala, 1997). The actual contribution of each food item to the total seasonal diet were derived using the dry weight per bite of each food item, proportional contribution to the total bites observed during direct observations and proportionate habitat use for foraging.

5.2.1 Diet Niche Width and Overlap

The basic approach to understand the prevalence of interspecific competition between sympatric species in terms of resource utilization pattern is to evaluate the diet niche breadth (Pianka, 1986; McDonald *et al.* 2000) and niche overlap (Reynolds & Meslow, 1984; Thill & Martin, 1986; Major & Sherburne, 1987). The diet niche breadths of these three sympatric species were evaluated using Levin's standardized niche breadth measure (Krebs, 1989).

The most common resources measured in order to calculate overlap are food and space. Since, food is one of the most important dimensions of the niche; the analysis of dietary overlap is closely related to the issue of niche specifications among sympatric species (Krebs, 1989). The comparison of niches of sympatric populations might give an insight to the understanding of potential for competition. Several measures of niche overlap have been proposed (Hurlbert, 1978; Abrams, 1980; Linton *et al.* 1981). Here, we used the Percent overlap indices (Schoener, 1970), which is the simplest measure of niche overlap to interpret.

The distinction between 'potential fundamental niche overlap' and 'expressed or realized resource use overlap' is critical. Overlap in the fundamental niche is indicative of a potential for competition when and where resources become limiting. However, some extraneous factors pertaining to interspecific relationships like predation, an additional competitor for one, but not both members of the competing pair, environmental perturbation at frequent interval etc. may facilitate their coexistence (Putman, 1996).

The seasonal dietary overlap between chital – cattle, chital – buffalo and cattle – buffalo was computed using proportion of each food item to total

bite count corrected with the proportionate habitat use for the foraging activities. The dietary overlap was also computed for different habitat types in different seasons for better understanding of their dietary overlap and subsequent forage competition. The dietary overlap computed for all three possible combinations i.e. chital-cattle, chital- buffalo and cattle-buffalo. The overlap between cattle and buffalo diet was computed just to understand the amplitude of resource use overlap pattern between sympatric species. The comparison of the overlap between cattle- buffalo with chital-cattle and chital-buffalo helps better interpretation of dietary overlap.

5.2.2 Chemical composition of major seasonal dietary items of chital, cattle and buffalo

The chemical analysis of the main food plants (Milner & Gwynne, 1974) is one of the principal ways of assessing the forage quality in ruminants as summarized by Mitchell *et al*. (1977). The seasonal variation in the chemical composition of herbivore food items is brought about by plant phenology (Blair *et al.* 1977; Hanley & Brady, 1977). In many previous studies (Sinclair, 1977; Jarman & Sinclair, 1979; Owen-Smith, 1982) variation in the crude protein content of grasses, forbs and woody dicotyledonous has been attributed to the seasonality. Digestibility is inversely related to crude fiber content, which increases with the maturity of the plants (Blair *et al.* 1977). The main components of the crude fiber contents i.e. cellulose and lignin increases with the plant maturity (Johnson *et al*. 1968; Torgerson & Pfander, 1971; Blair *et al*. 1977). The levels of crude protein and crude fibre in the rumen content have proved to be reliable indices of forage quality in cervids (Klein, 1962; Stain & Crisp, 1978).

Nutritional quality of seasonal food items which contributed more than 5 % of the total dry biomass of the diet of chital, cattle and buffalo were estimated in the laboratory. Crude protein, measured as nitrogen × 6.25, was determined by the Kjeldahl procedure (AOAC, 1987). The crude fibre components i.e. Neutral Detergent Fiber (NDF), Acid Detergent Fiber (ADF), and Acid Detergent Lignin (ADL) were determined using standard detergent methods (Goering & Van Soest 1970; Van Soest, 1982). Following this technique soluble cell content, hemicellulose, cellulose, lignin and acid

insoluble ash were computed for the major food items of chital, cattle and buffalo. The major (or macro) minerals in the solution in the rumen serve a number of generalized functions in addition to specific functions within cells and tissues (Church, 1976). The macro mineral content of seasonal food items like Sodium (Na), Potassium (K), Calcium (Ca) and Magnesium (Mg) were analyzed using standard analytical procedures outlined by Association of the Official Agricultural Chemists (AOAC, 1987).

5.3 Results

5.3.1 Detailed food habits of chital, cattle and buffalo

A total of 106 different food items including 100 different species of grasses, forbs, dicotyledonous herbs and leaves as well as fruits of tree were eaten by chital, cattle and buffalo during two consecutive years (Appendix - 1). Chital were seen feeding on 68 plant species while cattle and buffalo fed on 74 and 75 plant species, respectively. The seasonal account of the food items in chital cattle and buffalo diets for all six seasons is given in the Table-5.1. There was no major difference observed in the contribution of different food items within season between the two years; and hence observations were

pooled for each season.

Table- 5.1: Comparative account of seasonal habitat-wise foraging, food items and sampling effort for chital, cattle and buffalo in eastern Gir.

		Habitat use						No. Individuals			No. of food sps			no. bites		
Season	Habitat	chital	(SE)	Cattle	(SE)	buffalo	(SE)	chital	cattle	buffalo	chital	cattle	buffalo	chital	cattle	buffalo
Monsoon 04	*Acacia Ziziphus*	0.76	0.08	0.22	0.05	0.22	0.05	23	3	9	38	21	7	2248	3534	2594
	Anogeissus mixed	0.12	0.06	0.34	0.07	0.34	0.07	9	4	5	28	14	13	1527	953	1858
	Riverine	0.11	0.06	0.32	0.07	0.32	0.07	34	23	27	13	24	26	1006	2065	1983
	*Boswelia - Lanea – Terminalia**			0.12	0.09	0.12	0.09		7	4		12	14		2207	864
Winter 05	*Acacia Ziziphus*	0.63	0.06	0.38	0.05	0.34	0.05	17	10	20	6	3	17	831	994	2556
	Anogeissus mixed	0.21	0.06	0.39	0.05	0.43	0.05	16	14	19	15	9	16	719	1092	2602
	Riverine	0.17	0.06	0.04	0.01	0.05	0.01	24	12	20	23	22	8	919	1688	772
	Boswelia - Lanea - Terminalia			0.19	0.04	0.21	0.04		4	6		5	5		1186	1934
Summer 05	*Acacia Ziziphus*	0.61	0.10	0.33	0.09	0.29	0.08	14	11	12	15	15	13	1802	1270	1580
	Anogeissus mixed	0.11	0.04	0.35	0.04	0.42	0.07	7	6	8	16	7	4	2354	1301	1764
	Riverine	0.28	0.11	0.11	0.05	0.06	0.03	15	13	16	17	11	14	2310	1160	1110
	Boswelia - Lanea - Terminalia			0.21	0.07	0.23	0.05			2	3	4	5		738	811
Monsoon 05	*Acacia Ziziphus*	0.71	0.10	0.33	0.09	0.16	0.04	21	12	18	14	21	26	2096	2191	3153
	Anogeissus mixed	0.23	0.01	0.43	0.07	0.44	0.06	16	15	14	16	14	22	1828	1640	1545
	Riverine	0.08	0.05	0.02	0.01	0.03	0.01	26	16	20	18	25	40	1922	1848	2452
	Boswelia - Lanea - Terminalia			0.22	0.065	0.37	0.17		2	1		5	4		267	104
Winter 06	*Acacia Ziziphus*	0.74	0.04	0.37	0.09	0.27	0.07	22	7	7	16	19	22	2147	1254	1412
	Anogeissus mixed	0.06	0.03	0.36	0.07	0.45	0.06	14	7	9	7	21	22	609	1665	2162
	Riverine	0.20	0.05	0.05	0.02	0.07	0.03	24	8	13	25	27	36	983	1589	2088
	Boswelia - Lanea - Terminalia			0.22	0.06	0.21	0.04		2	3		5	7		307	405
Summer 06	*Acacia Ziziphus*	0.72	0..05	0.32	0.08	0.31	0.08	11	13	11	10	23	16	1829	1520	1741
	Anogeissus mixed	0.07	0.02	0.29	0.05	0.41	0.05	9	14	8	14	13	19	1694	1843	1513
	Riverine	0.20	0.04	0.11	0.12	0.07	0.02	9	11	27	13	19	23	1297	1520	1480
	Boswelia - Lanea - Terminalia			0.28	0.09	0.21	0.04		13	15		6	8		1209	1764

* chital were never reported foraging in this habitat.

The comparative account of the seasonal food habits of chital cattle and buffalo for different habitat types is given below.

5.3.1.1 Winter

Chital was observed to depend chiefly on browse items. *Acacia sp.* and *Ziziphus sp.* contributed predominantly to the winter diet of chital, whereas cattle and buffalo diets were largely composed of grasses during same season. As discussed in the previous chapter, chital largely used the *Acacia - Ziziphus* scrubland for foraging while livestock foraged more in *Anogeissus* mixed habitat and *Boswelia – Lanea – Terminalia* habitat. This is well reflected in the food habit study too. The maximum number of food items (37) obtained by chital was from the moist mixed riverine habitat compared to *Acacia - Ziziphus* scrubland (24) and *Anogeissus* mixed vegetations (17). However, the maximum dry biomass contribution to chital diet was from *Acacia - Ziziphus* scrubland (87.1 %). Similarly, like chital, the maximum number of food items of cattle (38) and buffalo (41) were observed obtained from the riverine habitat. However the maximum dry biomass of livestock diets was from *Anogeissus* mixed (cattle- 43.2 & buffalo- 34.5 % dry biomass consumption) and *Boswelia – Lanea – Terminalia* (cattle- 25.6 % buffalo- 29.8 % dry biomass consumption) habitat The moist mixed riverine vegetation contributes little to total biomass consumption by any of these animals (chital- 8.9 %, cattle- 3.6 % & buffalo-2.8 % dry biomass consumption).

Among all consumed food items by chital, pods of *Acacia nilotica* contributed 63.15 % followed by the fruits of *Ziziphus mauritiana* (7.6 %) to the dry biomass of winter diet. The contribution of grasses was less than 5 % in the dry biomass of chital diet during winter (Table-5.2A), whereas dietary compositions of cattle and buffalos were largely contributed by grasses and forbs. *Heteropogon contourtus* was the major food item of cattle and buffalo, contributing 47.4 % and 36.1 % to the winter diets of cattle and buffalo, respectively. Hence, during winter chital was observed to be a browser and both cattle and buffalo were grazers (Table-5.2B & 5.2C).

Table- 5.2A: Percent dry biomass contribution of major food items to winter diets of chital in Gir forests.

Food item	*Acacia Ziziphus* A	*Anogeissus* mixed B	Riverine C	% Bite in diet D	Dry wt bite^{-1} E	Dry wt in 100 bites F	% dry wt in diet G
*Acacia nilotica F**	20.86	0.00	0.00	20.86	2.30	47.88	63.15
Ziziphus moritiana F	6.50	3.31	1.01	10.82	0.53	5.76	7.60
Acacia nilotica L	3.36	0.00	0.00	3.36	0.72	2.41	3.18
Ziziphus moritiana L	15.69	1.33	3.02	20.04	0.10	1.91	2.51
Paspalidium spp.	5.48	0.00	0.00	5.48	0.24	1.33	1.75
Aristida spp	2.07	0.00	1.14	3.21	0.24	0.78	1.03
Anogeissus latifolia L	0.00	1.02	1.32	2.33	0.32	0.75	0.98
Erogrostis Spp	1.70	0.00	0.00	1.70	0.33	0.56	0.74
Acacia catechu L	2.43	0.00	0.00	2.43	0.19	0.46	0.61
Peristrophe bicalyculata	0.00	0.00	1.35	1.35	0.33	0.44	0.59
Ficus benghalensis F	0.00	0.00	1.23	1.23	0.35	0.42	0.56
Barleria priontis	0.00	0.00	1.01	1.01	0.15	0.16	0.21
Others (< 5 %)	16.45	1.60	8.77	26.82	0.48	12.95	17.09

A = percentage of bites of a food item in *Acacia Ziziphus* scrubland multiplied by proportional foraging activity in *Acacia Ziziphus* scrubland for that season (From Habitat use chapter)

B = percentage of bites of a food items in *Anogeissus* mixed habitat multiplied by proportional foraging activity in *Anogeissus* mixed habitat for that season.

C= percentage of bites of a food items in riverine habitat multiplied by proportional foraging activity in riverine habitat for that season.

D = the sum of A + B + C (percentage of bites in actual diet).

E = dry weight of single bite of that particular food item.

F = contribution by dry weight of food items in 100 bites (D × E =F).

G = percentage contribution in dry weight to the actual diet [F $(\Sigma F)^{-1}$] ×100.

* F= fruits; L= leaves; FL= flower; and rest were grasses and forbs (leaves & stem both consumed).

Table- 5.2B: Percent dry biomass contribution of major food items to winter diets of cattle in Gir forests.

Food item	*Acacia Ziziphus* A	*Anogeissus* mixed B	Riverine C	*Boswelia Lanea Terminalia* D	% Bite in diet E	Dry wt bite^{-1} F	Dry wt in 100 bites G	% dry wt in diet H
Heteropogon contorius	4.97	14.88	0.00	8.89	28.74	1.91	54.89	47.36
Aristida spp	19.93	3.06	0.86	1.59	25.45	0.51	13.09	11.29
Apluda mutica	3.49	6.25	0.41	0.00	10.15	1.15	11.66	10.06
Eremopogon foveolatus	0.00	2.32	0.00	3.98	6.30	2.19	13.79	11.90
Panicum spp	0.00	2.41	0.00	0.00	2.41	0.67	1.62	1.40
Leucas cephalotes L*	0.00	2.83	0.43	0.00	3.27	0.35	1.14	0.98
Themeda cymbaria	0.00	2.32	0.00	3.03	5.35	0.47	2.52	2.17
Paspalidium spp.	2.29	0.00	0.00	0.00	2.29	0.32	0.73	0.63
Heteropogon triticeous	0.00	0.00	0.29	0.00	0.29	1.28	0.36	0.31
Ischaemum pilosum	0.00	0.00	0.26	0.00	0.26	1.32	0.35	0.30
Others (< 5 %)	7.45	4.05	2.31	1.68	15.49	1.02	15.77	13.60

A = percentage of bites of a food item in *Acacia - Ziziphus* scrubland multiplied by proportional foraging activity in *Acacia - Ziziphus* scrubland for that season (From Habitat use chapter).
B = percentage of bites of a food items in *Anogeissus* mixed habitat multiplied by proportional foraging activity in *Anogeissus* mixed habitat for that season.
C= percentage of bites of a food items in riverine habitat multiplied by proportional foraging activity in riverine habitat for that season.
D= percentage of bites of a food items in *Boswelia – Lanea - Terminalia* habitat multiplied by proportional foraging activity in *Boswelia – Lanea - Terminalia* habitat for that season.
E = the sum of A + B+ C + D (percentage of bites in actual diet).
F = dry weight of single bite of that particular food item.
G = contribution by dry weight of food items in 100 bites (D × E =F).
H = percentage contribution in dry weight to the actual diet [F $(\Sigma F)^{-1}$] ×100.

* F= fruits; L= leaves; FL= flower; and rest were grasses and forbs (leaves & stem both consumed).

Table- 5.2C: Percent dry biomass contribution of major food items to winter diets of buffalo in Gir forests.

Food item	*Acacia Ziziphus* A	*Anogeissus* mixed B	Riverine C	*Boswelia Lanea Terminalia* D	% Bite in diet E	Dry wt bite^{-1} F	Dry wt in 100 bites G	% dry wt in diet H
Heteropogon contorius	11.40	0.00	0.00	11.24	22.64	2.94	66.45	36.12
Eremopogon foveolatus	0.00	5.18	0.00	5.33	10.51	3.49	36.64	19.91
Aristida sps.	7.95	5.39	0.00	0.00	13.34	1.09	14.58	7.92
*Aegel marmelos L**	0.00	12.53	0.00	0.00	12.53	0.98	12.22	6.64
Sehima nervosum	0.00	2.56	0.00	0.00	2.56	2.12	5.41	2.94
Apluda mutica	0.00	3.76	0.00	1.55	5.31	1.39	7.39	4.02
Ziziphus mauritiana L	0.00	2.26	0.70	0.00	2.96	0.86	2.55	1.38
Eragrostis poaeoides	1.88	0.00	0.00	0.00	1.88	1.27	2.38	1.30
Panicum spp.	1.89	0.00	0.00	0.00	1.89	1.10	2.08	1.13
Helicteres isora L	0.00	0.00	0.66	0.00	0.66	1.27	0.83	0.45
Barleria priontis	0.00	0.00	0.31	0.00	0.31	1.27	0.39	0.21
Ischaemum pilosum	0.00	0.00	0.30	0.00	0.30	1.27	0.38	0.20
Dichanthium annulatum	0.00	0.00	0.29	0.00	0.29	1.27	0.37	0.20
Leucas cephalotes L	0.00	0.00	0.33	0.00	0.33	0.52	0.17	0.09
Wrightia tinctoria L	0.00	0.00	0.25	0.00	0.25	0.59	0.15	0.08
Paspalidium spp	0.00	0.00	0.37	0.00	0.37	0.03	0.01	0.01
Others (< 5 %)	10.29	10.97	1.74	0.88	23.87	1.34	31.99	17.39

A = percentage of bites of a food item in *Acacia - Ziziphus* scrubland multiplied by proportional foraging activity in *Acacia - Ziziphus* scrubland for that season (From Habitat use chapter).

B = percentage of bites of a food items in *Anogeissus* mixed habitat multiplied by proportional foraging activity in *Anogeissus* mixed habitat for that season.

C= percentage of bites of a food items in riverine habitat multiplied by proportional foraging activity in riverine habitat for that season.

D= percentage of bites of a food items in *Boswelia – Lanea - Terminalia* habitat multiplied by proportional foraging activity in *Boswelia – Lanea - Terminalia* habitat for that season.

E = the sum of A + B + C + D (percentage of bites in actual diet).

F = dry weight of single bite of that particular food item.

G = contribution by dry weight of food items in 100 bites (D × E =F).

H = percentage contribution in dry weight to the actual diet [F $(\Sigma F)^{-1}$] ×100.

* F= fruits; L= leaves; FL= flower; and rest were grasses and forbs (leaves & stem both consumed).

5.3.1.2 Summer

Summer is hot and dry season considered as a resource crunch period in Gir. During summer too, chital diet was largely constituted by browse; whereas cattle were observed to be an intermediate feeder and buffalo, a grazer. Chital were observed foraging maximum in the *Acacia - Ziziphus* scrubland during summer. However, foraging by livestock had considerably decreased in the *Acacia - Ziziphus* scrubland during summer (Chapter – 4, Figure-4.8 & 4.5). The number of food items were almost equally obtained by chital from different habitats i.e. *Acacia - Ziziphus* scrubland (21), *Anogeissus* mixed habitat (23) and moist mixed riverine habitat (25). Chital diet was largely composed of browse items i.e. they fed largely on the pods of *Acacia nilotica* (20 % of the total dry biomass composition of summer diet), pods of *Acacia leucoplea* (11.2 %) and pods of *Acacia catechu* (6.7 %) along with the green leaves of *Schleichera olesa* (11.7 %) and *Ziziphus mauritiana* leaves (8.2 %). Whereas, in case of cattle and buffalo, number of food items were more from *Acacia - Ziziphus* scrubland (31 & 24 food items, respectively) and moist mixed riverine habitat (cattle- 23 & buffalo – 32 food items) compared to *Anogeissus* mixed habitat (cattle 16 & Buffalo 9 food items, respectively). Although the number of food items of cattle and buffalo were more in *Acacia - Ziziphus* scrubland and riverine habitats, the dry biomass contribution was maximum from *Anogeissus* mixed habitat (cattle- 43.3 % & 46.6 % dry biomass consumption) and *Boswelia – Lanea - Terminalia* habitat (cattle- 6.6 % & buffalo 24.9 % dry biomass consumption). Livestock diets (dry biomass consumption) were largely contributed by three grass species i.e. *Apluda mutica* (cattle- 18.9 % & buffalo- 35.0 %), *Eremopogon foveolatus* (cattle- 14.0 % & buffalo- 18.9 %) and *Aristida* sps (cattle- 11.0 % & buffalo- 17.4 %), mostly found in *Anogeissus* mixed habitat. These three grasses contributed more than 44 % dry biomass consumption by cattle and more than 71 % by buffalo during summer.

The summer diet of chital was predominantly contributed by browse items (Table-5.4A); whereas, cattle were observed to be mixed feeders as grazing and browsing contributed 50 % and 26 %, respectively, to the total dry biomass

consumption during summer (rest of the food items included dry litter, dry annuals etc. which contributed less than 5 % of the total seasonal bite count) (Table- 5.3 B). Buffalo were largely grazers during same period (77 % grazing contribution compared to 11 % browsing to the dry biomass consumption) (Table- 5.3C).

Table-5.3 A: Percent dry biomass contribution of major food items to summer diets of chital in Gir forests.

Food item	*Acacia Ziziphus* A	*Anogeissus* mixed B	Riverine C	% Bite in diet D	Dry wt bite^{-1} E	Dry wt in 100 bites F	% dry wt in diet G
Acacia nilotica F	5.01	0.00	0.00	5.01	2.52	12.61	19.96
Schleichera olesa L	0.00	0.00	5.09	5.09	1.46	7.41	11.73
Acacia leucophloea F	8.22	0.00	0.00	8.22	0.86	7.09	11.22
Ziziphus moritiana L	9.01	1.05	0.00	10.06	0.51	5.15	8.15
Acacia catechu F	6.05	0.00	0.00	6.05	0.70	4.25	6.72
Acacia leucophloea L	8.80	0.00	0.00	8.80	0.34	3.01	4.76
Aristida spp	8.16	1.86	0.00	10.02	0.23	2.35	3.72
Syzygium heyneanum F	0.00	0.00	2.94	2.94	0.55	1.62	2.56
Capparis sepiara L	0.00	0.00	2.36	2.36	0.45	1.06	1.68
Acacia nilotica L	7.92	0.75	0.00	8.67	0.09	0.79	1.25
Apluda mutica	0.00	2.07	0.00	2.07	0.34	0.71	1.12
Anogeissus latifolia L	0.00	0.81	0.00	0.81	0.52	0.42	0.66
Barleria priontis	0.00	0.00	2.54	2.54	0.15	0.39	0.62
Flacourtia indica L	0.00	0.00	1.46	1.46	0.24	0.36	0.57
Eremopogon foveolatus	0.00	0.82	0.00	0.82	0.38	0.31	0.50
Others (< 5 %)	13.43	2.01	9.65	25.09	0.62	15.66	24.78

Table-5.3 B: Percent dry biomass contribution of major food items to summer diets of cattle in Gir forests.

Food item	*Acacia Ziziphus* mixed A	*Anogeissus* mixed B	Riverine C	*Boswelia Lanea Terminalia* D	% Bite in diet E	Dry wt bite^{-1} F	Dry wt in 100 bites G	% dry wt in diet H
Apluda mutica	0.00	10.85	0.00	0.46	11.30	1.85	20.88	18.92
Eremopogon foveolatus	0.00	5.58	0.00	1.71	7.29	2.13	15.49	14.03
Ziziphus mauritiana L	6.99	0.00	3.85	0.00	10.84	0.99	10.73	9.72
Aristida spp	2.66	7.66	0.00	1.52	11.85	1.03	12.17	11.03
Embelica officainalis L	0.00	0.00	6.99	0.00	6.99	0.72	5.04	4.56
Anogeissus latifolia L	0.00	2.38	1.96	0.00	4.34	1.03	4.46	4.04
Bauhinia racemosa L	2.83	0.00	0.00	0.00	2.83	1.26	3.57	3.23
Wrightia tinctoria L	3.86	0.00	0.00	0.00	3.86	0.85	3.26	2.96
Sehima nervosum	0.00	2.87	0.00	0.61	3.48	0.99	3.45	3.12
Arundinella pumila	0.00	0.00	1.95	0.00	1.95	1.10	2.15	1.95
Moringa tinctoria L	0.00	0.00	1.61	0.00	1.61	0.58	0.93	0.84
Peristrophe bicalyculata	3.46	0.00	0.00	0.00	3.46	0.21	0.74	0.67
Capparis saparia L	2.45	0.00	0.00	0.00	2.45	0.16	0.40	0.36
Heteropogon triticeous	0.00	0.00	0.00	0.57	0.57	0.21	0.12	0.11
Themeda cymbaria	0.00	0.00	0.00	0.38	0.38	0.47	0.18	0.16
Others (< 5 %)	10.35	2.78	13.54	0.38	27.04	0.99	26.80	24.29

Table-5.3 C: Percent dry biomass contribution of major food items to summer diets of buffalo in Gir forests.

Food item	*Acacia Ziziphus* mixed A	*Anogeissus* mixed B	Riverine C	*Boswelia Lanea Terminalia* D	% Bite in diet E	Dry wt bite^{-1} F	Dry wt in 100 bites G	% dry wt in diet H
Apluda mutica	4.65	17.38	0.93	5.15	28.10	2.18	61.31	34.99
Aristida sps	5.09	11.28	0.00	5.29	21.66	1.40	30.42	17.36
Eremopogon foveolatus	0.00	7.98	0.00	5.44	13.42	2.47	33.18	18.94
Ziziphus mauritiana L	6.53	0.00	0.64	0.00	7.17	1.25	8.97	5.12
Panicum spp	0.00	2.70	0.00	0.00	2.70	1.42	3.83	2.18
Anogeissus latifolia L	2.01	0.00	0.82	0.00	2.83	1.34	3.81	2.17
Acacia nilotica	1.52	0.00	0.00	0.00	1.52	1.45	2.21	1.26
Ziziphus oenoplia L	1.87	0.00	0.00	0.00	1.87	0.62	1.16	0.66
Terminalia crenulata L	0.00	0.00	0.44	0.00	0.44	1.93	0.85	0.49
Morinda tinctoria L	0.00	0.00	0.59	0.00	0.59	0.94	0.55	0.32
Themeda cymbaria	0.00	0.00	0.00	2.15	2.15	1.38	2.97	1.70
Capparis sepiara L	1.60	0.95	0.00	0.00	2.55	0.18	0.46	0.27
Heteropogon triticeous	0.00	0.00	0.00	1.31	1.31	1.38	1.81	1.03
Others (< 5 %)	6.81	3.04	2.37	4.92	17.14	1.38	23.67	13.51

5.3.1.3 Monsoon

Monsoon is the only growing period for most of the plant species in Gir. Hence, during monsoon food resources for herbivores are plentiful. During monsoon, chital was more of a grazer than a browser, as graze and browse items contributed 69.8 % and 30.2 %, respectively, to the dry biomass consumption of major food items (which contributed more than 5 % to the seasonal bite counts). Cattle and buffalo were also mostly grazers with more than 95 % and 93 % dry biomass of major graze items (which contributed more than 5 % of seasonal bite counts) in their diets, respectively. The use of moist mixed riverine habitat by chital, cattle and buffalo had decreased considerably during monsoon; and most of the foraging activity of these three animals was restricted to *Acacia - Ziziphus* scrubland. The maximum number of food items (38) as well as the dry biomass contribution to the monsoon diet composition of chital was from the *Acacia - Ziziphus* scrubland (Table- 5.2 & 5.4 A). Although livestock spent considerably more time in *Acacia - Ziziphus* scrubland for foraging, maximum dry biomass contribution to the monsoon diet compositions of cattle and buffalo was from the *Anogeissus* mixed habitat (Table-5.4 B & C).

Chital diet was largely made up of short annual grasses like *Paspalidium sp* (16.7 %), *Apluda mutica* (15.2 %) and *Cyperus nutans* (6.5 %); and tender leaves and flowers of *Acacia nilotica* (8.4 %) and *Xeromphis uliginosa* (4.8 %), respectively. Whereas, cattle and buffalo diets were largely contributed by long perennial grasses *Eremopogon foveolatus* (cattle – 31.9 % and buffalo – 27.8 %). The presence of a large number of palatable species available in different habitat is reflected in the contribution of 'others' (food items contributing less than 5 % to the total bite count) during monsoon.

Table-5.4 A: Percent dry biomass contribution of major food items to monsoon diets of chital in Gir forests.

.

Food item	*Acacia Ziziphus* A	*Anogeissus* mixed B	Riverine C	% Bite in diet D	Dry wt bite^{-1} E	Dry wt in 100 bites F	% dry wt in diet G
Paspalidium spp.	21.53	3.28	0.00	24.81	0.05	1.31	16.68
Apluda mutica	6.21	4.87	0.63	11.72	0.10	1.19	15.20
Acacia nilotica L	8.19	0.00	0.00	8.19	0.08	0.66	8.37
Cyperus nutans	5.79	0.00	0.00	5.79	0.09	0.51	6.47
Xeromphis uliginosa FL	7.13	0.00	0.00	7.13	0.05	0.38	4.84
Aristida spp	0.00	4.46	0.00	4.46	0.07	0.30	3.88
Anogeissus latifolia L	0.00	0.00	1.19	1.19	0.14	0.17	2.19
Echinochloa colonum	3.84	0.00	0.00	3.84	0.04	0.15	1.96
Wrightia tinctoria L	0.00	0.00	1.30	1.30	0.10	0.13	1.63
Eulophia spp L	0.00	0.00	1.21	1.21	0.10	0.11	1.46
Securingea leucopyrus L	0.00	0.00	0.85	0.85	0.10	0.08	1.04
Barleria priontis	0.00	0.00	0.87	0.87	0.09	0.08	0.98
Others (< 5 %)	24.69	5.16	3.19	33.05	0.08	2.77	35.30

Table-5.4 B: Percent dry biomass contribution of major food items to monsoon diets of cattle in Gir forests.

Food item	*Acacia Ziziphus* A	*Anogeissus* mixed B	Riverine C	*Boswelia Lanea Terminalia* D	% Bite in diet E	Dry wt bite^{-1} F	Dry wt in 100 bites G	% dry wt in diet H
Eremopogon foveolatus	4.45	9.67	1.00	2.62	17.74	1.06	18.80	31.85
Apluda mutica	3.18	9.59	3.43	8.25	24.45	0.48	11.81	20.01
Themeda cymbaria	6.48	0.00	0.00	0.00	6.48	0.89	5.74	9.72
Heteropogon contorius	5.68	0.00	0.00	3.39	9.08	0.35	3.15	5.34
Leucas cephalotes L	0.00	0.00	3.84	0.00	3.84	0.45	1.73	2.93
Aristida spp	0.00	3.98	0.93	0.00	4.91	0.27	1.35	2.28
Borreria stricta L	0.00	0.00	2.31	0.00	2.31	0.13	0.29	0.50
Chionachne koenigii	0.00	0.00	0.00	0.91	0.91	0.52	0.47	0.80
Others (< 5 %)	7.49	12.92	7.80	2.07	30.28	0.52	15.70	26.59

Table-5.4 C: Percent dry biomass contribution of major food items to monsoon diets of buffalo in Gir forests.

Food item	*Acacia Ziziphus* A	*Anogeissus* mixed B	Riverine C	*Boswelia Lanea Terminalia* D	% Bite in diet E	Dry wt bite^{-1} F	Dry wt in 100 bites G	% dry wt in diet H
Apluda mutica	7.65	17.97	2.55	5.28	33.45	0.71	23.85	24.65
Eremopogon foveolatus	2.83	4.59	2.06	6.74	16.22	1.66	26.92	27.82
Heteropogon contorius	0.00	6.26	0.00	2.26	8.52	0.46	3.88	4.01
Leucas cephalotes L	1.27	0.00	2.81	0.00	4.07	0.52	2.11	2.18
Aristida sps	1.02	3.49	0.00	2.68	7.19	0.36	2.56	2.64
Heteropogon triticeous	1.91	0.00	0.00	0.00	1.91	0.94	1.79	1.85
Helicteres isora L	0.00	0.00	1.47	0.00	1.47	0.91	1.33	1.38
Sehima nervosum	0.00	0.00	0.00	2.45	2.45	0.78	1.91	1.97
Borreria stricta L	0.00	0.00	0.00	1.46	1.46	0.78	1.14	1.17
Themeda cymbaria	1.26	0.00	0.00	0.00	1.26	0.70	0.88	0.91
Others (< 5 %)	3.15	14.35	8.26	13.16	38.93	0.78	30.39	31.41

5.3.1.4 Overall annual diet compositions of chital, cattle and buffalo

Chital was observed to depend largely on browse items as overall annual diet of chital was largely composed of various browse items as browsing contributed more than 74 % of the dry biomass of the major food items (which contributed more than 5 % to the seasonal bite counts); whereas annual diets of livestock i.e. cattle and buffalo, were chiefly composed of grasses as different grasses and forbs contributed 70 % and 72 % of the dry biomass of the major food items of cattle and buffalo, respectively. Chital food items mainly included leaves and pods of three *Acacia* sps (39.7 % of total dry biomass of chital diet), leaves and fruits of two *Ziziphus sps* (6.1 %) along with three annual grasses viz. *Paspalidium sp* (6.1 %), *Apluda mutica* (5.4 %) and *Aristida sp* (2.9 %). Unlike chital, livestock diets chiefly included perennial grasses like *Eremopogon foveolatus* and *Heteropogon contorius*; *Eremopogon foveolatus* contributed 19.3 % and 22.2 % dry biomass to cattle and buffalo diets, while *Heteropogon contorius* contributed 17.6 % 13.4 % dry biomass to cattle and buffalo diets (Table- 5.5).

Table-5.5: Percent contribution of major food items (< 5% bite counts) to annual diet compositions of chital, cattle & buffalo in Gir Forests.

Food Items (part of plant)	Chital	Cattle	Buffalo
Acacia catechu F[1]	2.24	-	-
Acacia catechu L[2]	0.20	-	-
Acacia leucophloea F	3.74	-	-
Acacia leucophloea L	1.59	-	-
Acacia nilotica F	27.70	-	0.42
Acacia nilotica L	4.27	-	-
Aegel marmelos L	-	-	2.22
Anogeissus latifolia L	1.28	1.35	0.72
Apluda mutica	5.44	16.33	21.22
Aristida spp	2.87	8.20	9.31
Arundinella pumila	-	0.65	-
Barleria priontis	0.60	-	0.07
Bauhinia racemosa L	-	1.08	-
Borreria stricta	-	0.17	0.39
Capparis sepiara L	0.56	0.12	0.09
Chionachne koenigii	-	0.27	-
Cyperus nutans	2.16	-	-
Dichanthium annulatum	-	-	0.07
Echinochloa colonum	0.65	-	-
Embelica officainalis L	-	1.52	-
Eremopogon foveolatus	0.17	19.26	22.23
Eragrostis poaeoides	0.25	-	0.43
Eulophia spp L	0.49	-	-
Ficus benghalensis F	0.19	-	-
Flacourtia indica L	0.19	-	-
Helicteres isora L	-	-	0.61
Heteropogon contorius	-	17.57	13.38
Heteropogon triticeous	-	0.14	0.96
Ischaemum pilosum	-	0.10	0.07
Leucas cephalotes L	-	1.30	0.76
Moringa tinctoria L	-	0.28	0.11
Panicum spp	-	0.47	1.10
Paspalidium spp.	6.14	0.21	0.00
Peristrophe bicalyculata	0.20	0.22	-
Schleichera olesa L	3.91	-	-
Securingea leucopyrus L	0.35	-	-
Sehima nervosum	-	1.04	1.64
Syzygium heyneanum L	0.85	-	-

Food Items (part of plant)	Chital	Cattle	Buffalo
Terminalia crenulata L	-	-	0.16
Themeda cymbaria	-	4.02	0.87
Wrightia tinctoria L	0.54	0.98	0.03
Xeromphis uliginosa FL[3]	1.61	-	-
Ziziphus mauritiana F	2.53	-	-
Ziziphus mauritiana L	3.55	3.24	2.17
Ziziphus oenoplia L	-	-	0.22
Others (< 5 %)	25.72	21.49	20.75

L[1]- Leaves, F[2]- Fruit, FL[3] – Flower, rest were grasses and forbs (leaves & stem both consumed).

5.3.2 Chemical composition of chief dietary items of chital, cattle and buffalo

The results of the chemical analysis of major food items which contributed more than 5 % to the total dry biomass of diet of either chital or cattle and buffalo are summarized in Table-5.6.

The range of crude protein content in all major dietary items was 1.69 % in *Aristida sp* during summer and 17.97 % in *Acacia nilotica* in winter. Overall, major food items of chital, cattle and buffalo were relatively rich in carbohydrates and more digestible, as cell wall content was less lignified compared to summer food. Among all food items, *Aristida sp* was the lowest in protein content (winter- 1.83 % & summer- 1.69 %) but comparatively higher hemicellulose content (winter- 11 % & summer- 9.2 %) and cellulose content (winter- 31 % & summer- 34 %) with less than 10 % lignifications during winter as well as summer which provides a major source of carbohydrates and in turn energy. Browse items were consistently higher in crude protein content and lower in ash content compared to grasses during winter, summer as well as monsoon, too. Mineral contents in major food items remained relatively higher during monsoon which is the only growing phase and then decreased during subsequent dry spell i.e. winter and summer.

Table-5.6: Nutritional value of major food items of chital, cattle and buffalo in different seasons in the intensive study area of Gir forests.

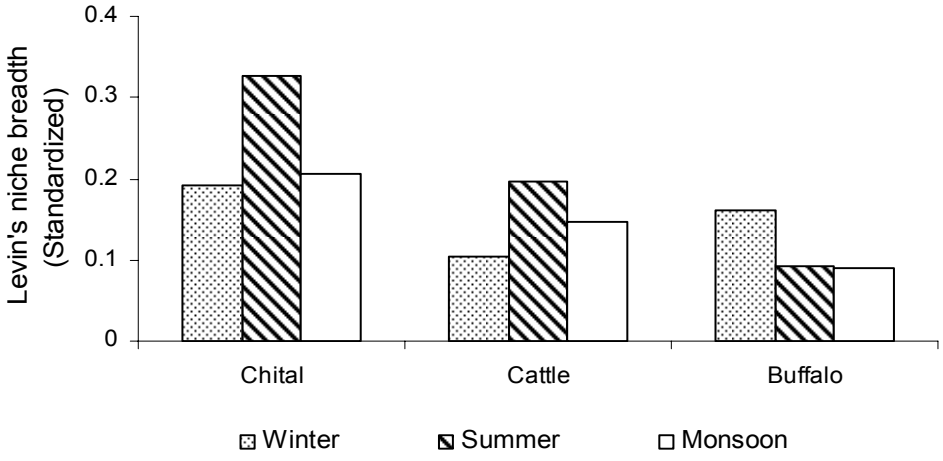
Season	Botanical names	Diet % chital	cattle	buffalo	%Crude protein	% Cell sol.	% Hemi cellulose	% Cellulose	% Lignin	% Ash	% Na	% K	% P	% Ca	% Mg
Winter	*Acacia nilotica F*	63.15	*	*	12.10	76.49	9.28	10.79	3.25	0.11	0.02	0.69	0.14	0.42	0.13
	Acacia nilotica L	3.18	*	*	17.97	82.58	1.38	7.35	8.49	0.10	0.02	0.63	0.13	1.06	0.15
	Aristida spp	1.03	11.29	7.93	1.83	40.48	11.01	31.17	9.87	7.20	0.04	0.41	0.01	0.20	0.11
	Aegel marmelos	*	*	6.65	8.82	76.95	1.36	10.54	10.16	0.49	0.10	0.51	0.05	0.30	0.18
	Ziziphus moritiana F	7.60	*	*	5.76	64.64	0.87	8.90	25.46	0.06	0.04	0.94	0.04	0.17	0.10
	Apluda mutica	*	10.06	4.02	3.78	44.90	4.53	28.59	13.32	8.33	0.05	0.73	0.00	0.18	0.10
	Heteropogon contorius	*	47.36	36.22	2.09	47.29	4.43	32.13	10.60	5.28	0.07	0.37	0.00	0.26	0.16
	Eremopogon foveolatus	*	11.90	19.93	2.59	40.91	6.80	22.98	15.79	12.76	0.02	0.44	0.01	0.18	0.17
Summer	*Acacia nilotica F*	19.96	*	*	11.27	75.63	6.28	12.79	5.05	0.12	0.03	0.72	0.12	0.42	0.13
	Aristida spp	3.17	11.03	17.36	1.69	39.88	9.15	34.13	9.44	7.20	0.03	0.04	0.00	0.12	0.04
	Ziziphus mauritiana L	8.15	9.72	5.12	5.66	58.80	2.72	17.44	19.18	0.94	0.05	0.13	0.02	1.66	0.28
	Apluda mutica	1.12	18.92	34.99	2.49	37.96	5.33	34.87	12.61	8.61	0.05	0.16	BDL	0.14	0.09
	Acacia leucophloea F	11.73	*	*	12.58	64.05	3.06	18.13	14.67	0.04	0.03	0.79	0.10	0.65	0.18
	Acacia catechu F	6.72	*	*	9.14	50.70	2.76	28.05	18.33	0.09	0.03	0.28	0.05	0.43	0.11
	Eremopogon foveolatus	0.50	14.03	18.94	2.03	36.49	8.77	25.70	17.23	10.90	0.03	0.12	0.01	0.18	0.09
Monsoon	*Acacia nilotica L*	8.37	*	*	17.71	51.10	8.54	17.42	22.67	0.13	0.04	0.83	0.09	0.47	0.24
	Apluda mutica	15.20	20.01	24.65	8.84	47.16	7.70	29.91	11.11	3.56	0.04	1.22	0.08	0.16	0.08
	Paspalidium spp	16.68	*	*	13.62	59.72	6.44	18.59	10.85	4.00	0.40	0.32	0.35	0.42	0.47
	Themeda cymbaria	*	9.72	0.91	6.37	44.98	8.17	26.19	11.92	8.37	0.03	0.77	0.07	0.20	0.20
	Cyperus nutans	6.47	*	*	6.06	58.19	7.02	19.80	11.90	3.03	0.25	0.60	0.07	0.23	0.19
	Eremopogon foveolatus	*	31.85	27.82	4.87	40.40	7.93	23.09	18.32	10.13	0.05	0.66	0.03	0.26	0.16

L- Leaves; F- Fruits; rest includes grasses (blades & stem)

5.3.3 Diet niche breadths

The diet niche breadths of cattle and buffalo were relatively narrower than chital during all three seasons (Figure -5.1). The pattern of niche breadth fluctuations varied between chital and buffalo as well as cattle and buffalo; buffalo diet niche breadth was largest (0.16) during winter whereas chital (0.33) and cattle diet niche breadths were largest during summer (0.20). The pattern of seasonal fluctuations in diet niche breadths of chital and cattle were similar i.e. broader niche breadths during summer and narrower during winter, nevertheless chital had a broad niche breadth compared to cattle and hence chital was more generalized feeder.

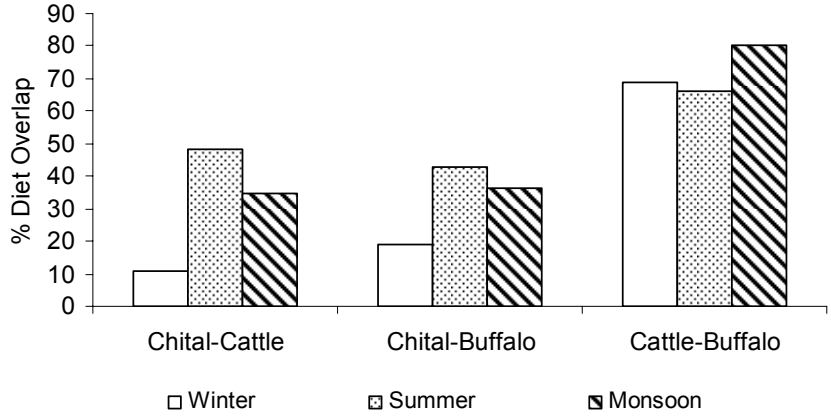
Figure – 5.1: Seasonal diet niche breadths of chital, cattle and buffalo.



5.3.4 Diet niche overlap

Major dietary overlap (> 65 %) was observed between cattle and buffalo across seasons. Whereas, dietary overlap between chital and livestock was comparatively smaller. The dietary overlap between chital and buffalo (48.0 %) as well as chital and cattle (42.8 %) was maximum during summer (Figure-5.2).

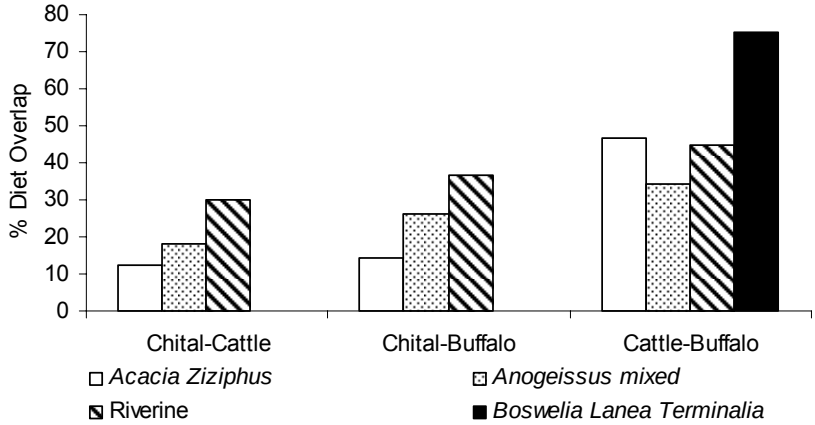
Figure - 5.2: Seasonal percent dietary overlaps among chital, cattle and buffalo in east Gir.



5.3.4.1 Habitat-wise seasonal dietary overlaps

During winter the food resources are abundant and diverse hence, dietary overlap never reported more than 40 % in habitat types between chital and livestock. Comparatively, diets overlap between chital and cattle was smaller compared to the diets overlap between chital and buffalo (Fig – 5.3). Maximum dietary overlap between chital and cattle (29.9 %), as well as chital and buffalo (36.6 %) was observed in riverine habitat. The dietary overlap between cattle and buffalo was higher in all habitats (< 40 %), especially, *Boswelia – Lanea – Terminalia* habitat (< 75 %).

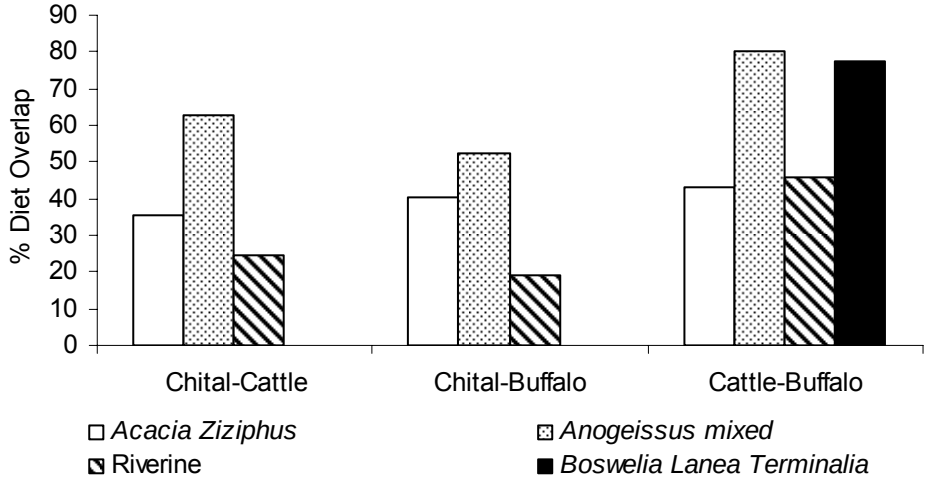
Figure - 5.3: Habitat wise Diet niche overlaps among chital, cattle and buffalo during winter (2005 & '06) in east Gir.



During summer, which is believed to be crucial period for resource competition between sympatric herbivore in dry tropical forests showed little higher dietary overlap between chital and cattle as well as chital and buffalo in the intensive study area (Figure – 5.4). Maximum dietary overlaps in all three combinations i.e. chital- cattle, chital- buffalo and cattle- buffalo had shifted

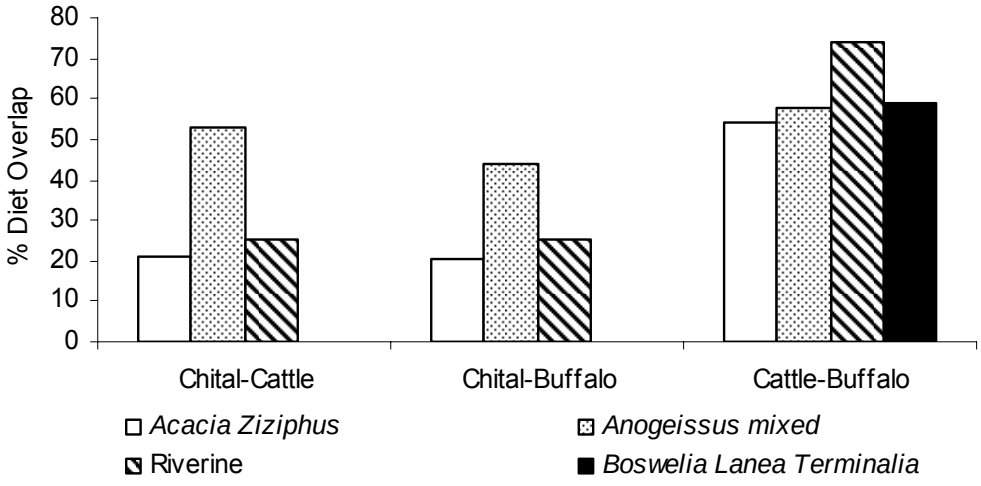
from riverine habitat during winter to *Anogeissus* mixed habitat during summer. The dietary overlap between cattle and buffalo was all time higher in *Anogeissus* mixed (80.4 %) and *Boswelia – Lanea – Terminalia* habitats (77.4 %) compared to winter and monsoon.

Figure – 5.4: Habitat wise Diet niche overlaps among chital, cattle and buffalo during summer (2004, '05 & '06) in East Gir.



The dietary overlaps between chital and cattle as well as chital and buffalo showed a decrease in all three foraging habitats of chital during monsoon. Among these three foraging habitats of chital, the dietary overlaps between chital – cattle and chital – buffalo remained relatively higher in *Anogeissus* mixed habitat; whereas, dietary overlaps substantially decreased in *Acacia - Ziziphus* habitat. Although dietary overlaps between chital and sympatric livestock decreased during monsoon, dietary overlaps increased between cattle and buffalo in all foraging habitats of livestock (Figure –5.5).

Figure – 5.5: Habitat wise Diet niche overlaps among chital, cattle and buffalo during monsoon (2004 & '05) in east Gir.



5.4 Discussion

The relationship of the diet selection and feeding ecology as well as behaviour with ungulate body size, morphology and physiology has been worked out in many previous research works and are cited in the 'Introduction' of the chapter (Section 5.1). Based on such generalities, chital and cattle-buffalo in this study should have clear feeding niche segregation, as chital is a small bodied herbivore compared to large bodied cattle and buffalos. The empirical observations on detailed food habits and foraging styles validated those generalities. Going one step ahead, an attempt was made to understand the mechanism of resource segregation between chital and livestock i.e. cattle and buffalo.

The amount of food that can be processed is a function of the cross section area of the gut; at the same time, metabolic needs are a function of the animal's weight. Thus, the larger the animal, more limiting is the rate at which food can be processed through the gut (Owen Smith & Novellie, 1982). Large generalist herbivores have adapted to using food which are abundantly available but of low nutritional value. Hence, large herbivores keep their gut full continuously and are therefore limited by how fast they can process the food rather than by how fast they can obtain it. It is well known that considering ungulate body size, metabolic requirement and rumen physiology, large ungulates must consume and digest abundant food while, smaller ungulate must feed on high nutrient quality food (Kleiber, 1961; Bell, 1971; Hofmann & Stewart, 1972). Cattle and buffalo with relatively larger body size, relied on bulky diet i.e. abundant and long perennial grasses while the diet of chital (relatively smaller ungulate) was often dominated by low fiber, high digestible browse and forbs.

The information on the food and feeding habits of chital as well as cattle and buffalo is scarce. According to Berwick (1974) and Johnsingh & Sankar (1991), cattle and buffalo are primarily grazers. Food habits of chital were studied during two previous studies (Berwick, 1974; Khan, 1993). Berwick (1974) reported that chital, along with other wild ruminants preferably consumed browse during the cafeteria as well as field trials. On the contrary, Khan (1993) reported chital a generalist feeder primarily feeding on grasses.

Even Schaller (1967), Sharatchandra & Gadgil (1975) Dinerstein (1980) and Tak & Lamba (1984) report that grass formed the bulk of chital diets while, browse items contributed marginally to it.

5.4.1 Seasonal diet niche breadth of chital, cattle and buffalo

Overall, diet niche breadth (number of bites of different food items in different proportionate use of foraging habitats) showed no consistent size related trend. However, during winter, food diversity was higher for buffalo followed by cattle and than by chital following the size related trend (Figure-5.1). Among these three ruminants, buffalo showed a consistently narrow diet niche breadth during all seasons while cattle and chital exhibit quite flexible diet niche breadth. However, cattle had the narrowest diet niche breadth i.e. food consisted fewer food items during monsoon while chital had relatively wider diet niche breadth during the same season which explains how two generalist feeders with differing body size and foraging styles operate when resources are abundant. Cattle being a relatively large bodied ruminant exhibited a 'time minimizing' foraging strategy in the presence of abundant food resources; whereas, small bodied chital opted for 'energy maximizing' foraging strategy. This suggests that, the within same foraging range chital obtained it's food from a wide variety of nutrient rich forage items, when available, to maximize the energy intake while livestock drew their food from few forage items which were abundant to maximize the bulk intake in short time.

5.4.2 Seasonal dietary overlaps of chital, cattle and buffalo

Contemporary competition theory suggests that sympatric animals should reduce competition by filling different food niches; that dietary overlap should be greater among similar sized animals; and that dietary overlap should increase with decreasing food resources (Schwartz & Ellis, 1981). The results obtained conform to the above principle. During winter the food resources are abundant and diverse, and hence little overlap was observed between chital and livestock (< 37 %). During summer, which is believed to be a peak period for resource competition between sympatric herbivores showed little higher dietary overlap between chital and cattle as well as chital and buffalo. In spite of relative resource poorness, the potential for forage competition between chital and cattle as well as chital and buffalo remains

only in *Anogeissus* mixed habitat. The dietary overlaps between chital and livestock i.e. cattle and buffalo was comparatively low during all seasons. However, within livestock i.e. between cattle and buffalo they had high dietary overlap. The patterns in dietary overlap between chital and cattle- buffalo could be attributed to the function of differential body size as well as evolutionary history (as chital being smaller cervid and cattle- buffalo being larger bovid).

Seasonal change in dietary overlap followed a size and evolution related trend i.e. differential foraging styles and behaviour of cervids and bovids. Overall, the dietary overlap was minimal between chital and livestock during all three seasons. However, seasonal variation in dietary overlaps followed patterns with respect to food abundance and their foraging styles. Dietary overlap between chital and cattle as well as buffalo was minimal during resource abundant season i.e. winter; and increases as dry season progresses (as food abundance decreases). Theoretical predictions and empirical findings (reviewed by Schoener, 1982) suggest increased diet divergence as food abundance decreases; however, Schwartz & Ellis (1981) reported otherwise. In this study too, it was evident that dietary overlap between chital and cattle- buffalo increases with a decrease in food abundance. Although dietary overlaps between chital and cattle- buffalo increased during resource poor season, dietary overlap was always smaller than the observed dietary overlap between cattle and buffalos, which could be attributed to the difference in their body size, mouthparts, and ecological adaptation to different feeding style and foraging behaviour.

5.4.3 Chemical composition of major dietary items of chital, cattle and buffalo

In empirical studies, herbivore selection for forage high in nutrient content has clearly been demonstrated for both wild (Swift, 1948; Heady, 1964; Hanley, 1984) and domestic (Cook, 1959; Senft *et al*. 1985) species. This selection is often dictated by N in the form of plant protein (Mattson, 1980).

During winter, the pods of *Acacia nilotica* alone contributed more than 63 % to the total dry biomass consumption by chital which was the best source of crude protein and carbohydrates with better digestibility (less

lignified) among other available food items. In case of livestock *Heteropogon contorius* was the main food item as it offered relatively high protein and cell soluble content, hence it was more energetic and digestible. The livestock i.e. cattle and buffalo were bulk eater as they fed more upon *H. contorius* which offered low protein (2.1 %), but high cell soluble content (47.3 %) and hence was more digestible, than *Apluda mutica* with relatively higher crude protein (3.8 %) and less cell soluble content (44.9 %). The result reflects that large herbivores can recycle urea using gut microbes for efficient nitrogen metabolism.

In Gir, summer is resource poor season which is well reflected in the result. More than 50 % of chital, cattle and buffalo diets were contributed by only four different food items. The same is reflected in poor protein content in most of the bulky graze food items of livestock. In case of chital, more than 38 % diet was contributed by fallen pods of three Acacia species as all *Acacia* species fruited during late winter months which offered high crude protein content and digestibility. However, none of these *Acacia* species contributed more than 5 % to either cattle or buffalo diets. *Apluda mutica*, a bulky grass contributed more than 18 % and 34 % to the summer diets of cattle and buffalo, respectively and therefore they could be considered as bulk feeders. The result indicated that *Apluda mutica* had low digestibility (high cell wall content) but high crude protein content compared to *Aristida sp.* The later one is a short grass and bears spikes to minimize grazing depredation. For livestock, it could be the best strategy during resource lean period to maximize the intake of bulky and protein rich *Apluda muitca* than more digestible but protein poor and thorny *Aristida sp*.

During monsoon, when diverse food resources were available and growing, diet of chital was more diverse as more than 54 % diet was formed by those food items which contributed less than 5 % the total monsoon diet of chital. During monsoon, crude protein and cell soluble contents were relatively higher in all major dietary food items. Seasonal change in the dietary protein and digestibility (cell soluble content) followed an expected trend. They were higher during growing period, as the growing season progresses, crude protein level decreases and plant structural components (fiber content) increase. Reduction in the diet quality of several food items from monsoon to

summer reflected in food habits of study animals (Table-5.7). In severely seasonal environments, grazing ungulates also time reproduction to coincide with onset of the growing season which brings a flush of young protein-rich grass which are high in other nutrients as well (McNaughton, 1990). All three ruminant species have been observed to have fawning just after the onset of monsoon, well synchronized with the growing period for forage resources.

The small body size and narrow snout/mouth opening enables chital to feed on *Paspalidium sp*, a patchily distributed short seasonal grass and *A. nilotica* leaves, tiny and protected by long thorns. The livestock i.e. cattle and buffalo largely fed upon *A. mutica* and *Eremopogon foveolatus*. Both of these grass species were relatively low in protein content and digestibility, yet widely distributed, tall and bulky food items.

Minerals play an important role in animal's diet. However, the role of minerals in diet selection remained unclear in this study. Tropical forages are of lower quality than temperate ones and are often chronically deficient in mineral elements (McDowell, 1985). Besides, digestibility, crude protein level and food item size (Belovsky, 1981) might have masked the effect of mineral concentration in the diet selection. Hence, the major food items which contribute more than 5 % dry biomass of the diet could not capture the mineral budgets of chital, cattle and buffalo. Most of these food items reported lower mineral content than requirement, reported by past studies on temperate ruminants (Halls, 1970).

During monsoon, mineral content along with crude protein level was high among grasses; and hence the diets of chital and cattle and buffalo were largely constituted by grasses during monsoon. Sodium and Potassium along with chlorine, as a salt help maintain water metabolism, osmotic pressure, acid-base equilibrium and passage of nutrients into cell. Potassium content of seasonal food items meet the normal requirement which is 0.2 – 0.3 % of dry weight of daily feed (Church, 1979). However, sodium content was low (NRC recommends 0.1 % salt in the diet dry matter for beef cattle). The requirement of phosphorus in temperate climate for normal growth and survival of heifers is 0.16 % (NAS-NRC, 1963) and game species is 0.30 (Magruder *et al.* 1956). The phosphorus content in the different seasonal food items were lower than the requirement in temperate climate, except *Paspalidium sp* during monsoon

(0.35 %). However, information on phosphorus requirement in tropical ungulates is lacking. The principal function of calcium along with phosphorus is the formation of skeleton. An adequate supply of calcium and phosphorus in a ratio of 1:2 and 2:1 along with vitamin D is desirable (Halls, 1970). The calcium content required for survival of white tailed deer was 0.3 % (Magruder *et al*. 1956); most of the major food items of these sympatric herbivore were less than the desirable level of calcium content (0.3 %).

The crude protein level in the diet of chital was comparatively high as the diet was largely contributed by browsing, but for cattle and buffalo diets which mostly included grasses, cell wall constituent (fiber content) was uniformly high across the seasons. This supports the theory proposed by Hoffman (1973) that large ungulates are bulk limited and that they maximize food intake, which in turn is constrained by dietary fiber. The foraging strategy of cattle and buffalos was observed to be time minimizers, whereas the chital foraging strategy was more energy maximizing. Livestock i.e. cattle and buffalo were observed to spend more time on foraging patches with abundant biomass as expected for time minimizer. Chital mostly foraged in the low biomass patch as expected for the energy maximizer in the foraging model developed by Bergman *et al*. (2001). It has also been pointed out that for plant foods; quality and abundance are inversely correlated (Wilson, 1976; Gaulin, 1979). The difference in the body sizes of chital and livestock results in the different energy requirement. Therefore chital and livestock foraging strategy differs as chital food items were more energetic than livestock ones. The optimization model developed by Bergman *et al* (2001) supports this empirical observation.

The food habit study of chital, cattle and buffalo clearly demonstrates their feeding strategies to optimize the nutrient intake during different seasons. The seasonal diet compositions of these sympatric herbivores exhibit little diet niche overlaps between chital and livestock. The results of this study help understand the ecological and evolutionary mechanism that, in turn, dictates the segregation of ecological niche within the same foraging range.

CHAPTER 6

Impact of Livestock on Vegetation and Response of Wild Ungulates

6.1 Introduction

Animals are expected to respond to the properties of different habitats. It is a well known fact that every organism is dependent on habitat for food, cover and other resources (Giles, 1978). Vegetation is one of the important aspects of animal's habitat as it bears a three fold importance in habitat ecology and management as it 1) physically represents the ecosystem, 2) forms the base of trophic pyramid and 3) acts as part of habitat where animals spend most or part of their life. Hence, the structure and function of wildlife-habitat relationship is a core concern of wildlife researchers and managers (see Bookhout, 1996).

Large mammalian herbivores not only depend on vegetation i.e. plant communities but also generate strong direct as well as indirect feedbacks in plant community composition and structure (Augustine, 1998). Herbivory can have mixed effects on species composition and community structure along with the spread of exotic plants at the landscape scale. High population densities of ungulates have been shown to change plant species composition, growth of tree, and to affect regeneration (Kie & Lehmkuhl, 2001). Ungulates can have strong effects on plant mortality and plant community composition, and can modify successional pathways and alter nutrient cycles at numerous spatial scales (McNaughton, 1976; Seagle *et al*., 1992; Hobbs, 1996; McLaren, 1996; Frank & Groffman, 1998; Ball *et al*., 2000; Coomes *et al*., 2003; Rooney & Waller, 2003).

Herbivore induced shift in species composition have been documented from grasslands through out the world (Ellison, 1960; Archer, 1989; Bosch, 1989, Noy-Meire *et al*. 1989, Westoby *et al*. 1989; Milton *et al*. 1994). Species composition based on biomass is one of the best indicators of species importance (Daubenmire, 1968). Further, biomass is closely related to forage availability and habitat carrying capacity (Bonham, 1989). The term 'biomass' is used as a synonym of 'phytomass' that is defined as '*the total mass of plants including dead attached parts, per unit area at a given time*' (Mitchell, 1983). The concept of rangeland condition and trend analysis is used to determine the current ecological status and has served as a basic tenet of rangeland management in the US in last century (Pickford & Reid, 1948;

Humphrey, 1949; Dyksterhuis, 1949; Parker, 1954; Jameson, 1970; Westoby *et al*. 1989; Fleischner, 1994; Hayes & Holl, 2003). Although experimental verification of the mechanism(s) contributing to herbivore induced species replacement has received remarkably low attention (Anderson & Briske, 1995; Barrett & Stilling, 2006).

Livestock grazing represents an anthropogenic alteration of natural disturbance regimes in plant communities (Hayes & Holl, 2003). Understanding the influence of domestic livestock upon native ecosystems is a difficult task. Available evidence indicates that livestock grazing has profound ecological costs. Autecological, synecological, and geomorphological studies have confirmed that native ecosystems get influenced by the presence of livestock. Three primary attributes of ecosystems have been elucidated: composition, function, and structure (Franklin *et al*. 1981).

The relationship between grazing and wildlife as well as their habitats is complex. Livestock grazing influences wildlife habitat by modifying plant biomass, species composition and structure components such as vegetation height and cover. The impacts of livestock grazing on wild ungulates can be classified as direct negative, indirect negative, operational and beneficial (Mackie, 1978). Many studies have documented the direct negative impact of livestock grazing on food resources of wild herbivores i.e. competition (Mackie, 1978; Voeten, & Prins, 1999; Prins, 2000; Mishra, 2001; Mishra *et al*. 2002; Mishra *et al*. 2004); on the other hand some studies showed the positive or beneficial effect of livestock grazing i.e. grazing facilitation (Vesey-Fitzgerald, 1960; Bell 1971; McNaughton 1976; Arsenault & Owen Smith, 2002; Rannestad, 2006).

As discussed in previous chapters, there was no sound evidence of direct negative impact of sympatric livestock grazing on wild ungulates. However, the indirect negative impact of sympatric livestock grazing remains unknown. Indirect negative impacts potentially include: 1) the reduction in the quantity and quality of the forage produced by gradual loss of vigour of some plants; 2) negative impact on the ability of forage plants to reproduce or regenerate; 3) reduction or elimination of locally important cover types and replacement by less favourable types or community, either by direct action or

by changing the rate of natural successional process; 4) general alterations and reduction in the species composition through selective foraging or other activities (Mackie, 1978).

This chapter deals with the indirect negative impact of livestock grazing on wild ungulates mediated through changes in plant community structure. The study involved an experimental approach to assess the forage availability in terms of biomass of graze and browse items as well as plant community composition in areas with sympatric livestock and areas devoid of livestock. The experimental design had controls for location (as *Maldhari* settlements are always located near good water availability) and for vegetation communities (as ecological properties of each community is likely different).

6.2 Methods

To understand, evaluate and quantify the consequences of sympatric livestock foraging on vegetation association I assessed 1) the short term impact of livestock grazing on ground cover composition and above ground biomass production; 2) short term (one growing season) as well as long term (> 5 growing seasons) impact of lopping and browsing by livestock on availability of browse biomass of *Anogeissus latifolia*, an important browse species for chital 3) long term livestock grazing impact on tree, shrub and herbaceous structure, recruitment and composition at varying distance criteria from active and old *Ness* sites evacuated more than 10 years. (Figure- 1.3, Chapter -1).

6.2.1 Assessment of livestock grazing impact on above ground biomass production

To quantify the impact of livestock grazing on the above ground biomass production, especially chital food, 10 wire mesh exclosures of 8m × 8m with 2m height and a mesh size of 3 cm × 3 cm were constructed in eastern Gir sanctuary (Tansley & Adamson, 1925; Holecheck, *et al*, 1982; Beebe *et al*. 2002). All exclosure sites were carefully selected to control for the vegetation type and other confounding factors. Out of ten exclosures, 3 exclosures were constructed within 500 m radius of each of three *Maldhari*

Ness sites located within the intensive study area (intensive livestock grazing & tramping); 3 exclosures were constructed at the periphery of the grazing area of these *Ness* sites (distance ranged 1.9 to 2.7 km) (moderate livestock grazing & trampling); and 4 exclosures were constructed in the area devoid of livestock (no livestock grazing and trampling) with similar adaphic characters and vegetation type (Figure - 6.1a). All exclosures were constructed in similar vegetation community with similar topographic features to control for variability in plant productivity associated with vegetation community structure, edaphic characteristics and topography. After excluding grazing by large herbivores for a full cycle of three seasons, 5 quadrates of 1m × 1m were clipped within each exclosure at the end of the winter 2006 i.e. February. Each quadrate clipped within the exclosure was paired with a quadrate sample clipped outside the exclosure in close proximity. A 50 cm strip of vegetation along the fence of the exclosure was excluded from the sampling to avoid any edge effect (Mullen & Rongstad, 1979; Jhala, 1991). The ground vegetation in each quadrate was sorted by species. Individuals of each species were clipped in a manner mimicking feeding by large herbivores (1 cm from ground level). Fresh and dry weight of each species was estimated by oven drying at 56 ^{0}C. Paired statistical comparisons were performed to study differences inside and outside the exclosures.

Figure- 6.1 A: Location map of exclosures, radiating transects and *Anogeissus* trees within intensive study area. Inset indicates the location of intensive site in Gir protected area.

6.2.2 Assessment of livestock browsing and lopping by *Maldhari* on *Anogeissus latifolia.*

Annual browse production can be most accurately measured by clipping and weighing twigs during the growing season (Harlow, 1977). *Anogeissus latifolia* was selected for the browse biomass estimation experiment as it is an important and abundant browse species for domestic and wild ungulates in eastern Gir (Berwick, 1974). Fresh growth is generally lopped and fed to livestock during resource crunch period i.e. late summer. Lopping can potentially have three consequences 1) it reduces available browse for wild ungulates or 2) stimulate lateral growth below the browse line thereby increasing browse availability to wild ungulates, and 3) continued high intensity lopping may reduce plant survival or seed production affecting recruitment. The available biomass of *Anogeissus latifolia* for browsing by wild and domestic ungulates was estimated on paired lopped v/s unlopped similar size trees and areas with and without livestock. For browse biomass estimation on lopped v/s unlopped trees, 30 matching pairs of similar GBH, height and canopy of *Anogeissus latifolia* tree with available browse within the reach of domestic and wild ungulates were identified within the vicinity of a *Maldhari* settlement (Figure - 6.1a). One tree in each matching pair was lopped during late summer i.e. May 2005. Later, all the 60 trees i.e. 30 pairs were protected against further lopping and browsing till next growing season. Fresh biomass on lopped and unlopped trees was compared using paired *t* test (Zar, 1984). Further 30 pairs of *Anogeissus latifolia* trees were randomly selected in areas with livestock and devoid of livestock to assess the effect of long term lopping and browsing by domestic livestock on browse availability (Figure - 6.1a). Browse availability in areas used by livestock in comparison to ungrazed areas was estimated by measuring diameters of all twigs with fresh growth of browse material within the reach of wild ungulate in next growing period (11 months). Fresh weight was computed using twig diameter-weight regression (Ruyle *et al*. 1983) fresh biomass on *Anogeissus latifolia* trees in areas used by livestock and devoid of livestock was compared using ANCOVA (Zar, 1984), keeping presence of livestock as main effect and GBH as covariate.

6.2.3 Assessment of trends in tree, shrub and palatable browse and ground cover and subsequent use by wild herbivores.

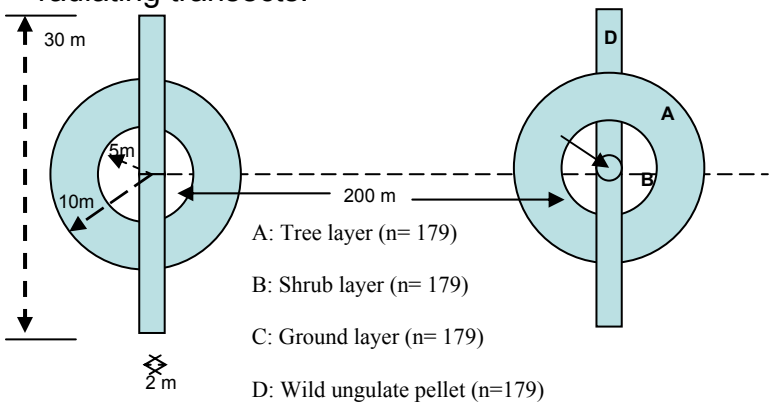
The impact of *Maldhari* livestock on structure, composition and regeneration in different vegetation associations as well as use by wild herbivore was assessed on radiating transects (Figure - 6.1a). Since livestock were likely to impact areas near the *Ness* sites the most, with a decreasing impact as distance from active *Ness* sites increases (Riginos & Hoffman, 2003). Also the locations of *Ness* sites are selected by *Maldhari* in areas of perennial water sources, thus it was likely that detected trends in vegetation with increasing distance from *Ness* sites were a result of sampling along an aridity gradient. To control for this effect of *Ness* site location, sampling was done on 19 radiating transects originating from 3 active and 2 old *Maldhari* settlements evacuated more than 10 years. Out of 19 radiating transects, 12 radiating transects were sampled in the livestock grazing area of three neighbouring *Maldhari Ness* sites; whereas, 7 radiating transects laid around two evacuated *Maldhari* settlements and hence devoid of livestock grazing with relatively similar physical characteristics as well as vegetation types. Since the active sites were in proximity to each other, radiating transect lengths as well as their spatial arrangements were adjusted accordingly so they did not ingress into the grazing area of neighbouring *Ness* site. The length of each transect depended on the periphery of foraging area of respective *Ness* in that direction which ranged between 1.5 to 3.0 km in length; whereas, in case of evacuated sites the length of the transect was fixed to 2 km. In case of overlapping grazing areas of neighbouring ness sites the zone of overlapping livestock grazing was excluded from the sampling.

Tree, shrub, herbaceous layer, human disturbance and the presence of ungulate pellets were assessed at an interval of 200 m on 10m, 5m, 1m, radius circular plots and 30m × 2m quadrate, respectively (Figure - 6.1b). At every 200 m on the radiating transect, in each 10m circular plot, tree species, tree height and Girth at Breast Height (GBH) were recorded. The individuals of tree species with > 10cm GBH and >2m height were considered as trees. Lower girth classes (<10 cm) of same species were considered as regeneration. A nested circular plot of 5 m radius was demarcated in the 10 m radius tree sampling plot for the assessment of shrub density and diversity

using the same centre. The woody species which had GBH < 10 cm and height between 0.5m and 2m were considered as shrubs (Muller-Dombois & Ellenberg, 1974). For ground cover, a nested circular plot with 1 m radius was demarcated in 5 m radius shrub plot with same centre. Ocular estimation of percent ground covered by green grass, dry grasses, forbs, weed and barren ground was made. The contribution of each herbaceous species to total ground cover was also estimated visually (Muller Dombois & Ellenberg).

Pellet densities of wild ungulates at every 200 m sampling site was estimated using 30 m × 2 m quadrate, perpendicular to the transect line (15 m on either side of the transect) to assess the use by wild and domestic herbivores viz. chital, sambar, nilgai, chowsinga, chinkara, wildpig as well as cattle & buffalo.

Figure- 6.1 B: Diagrammatic representation of vegetation sampling plots on radiating transects.



6.2.4 Plant community classification & community parameters

Plant communities were using Two Way INdicator SPecies ANalysis (TWINSPAN) (Hill, 1979). The pseudospecies cut off levels for abundance were chosen based on the field knowledge of abundance of major tree species within intensive study area, instead of default values in the software program PC-ORD. The selected cut off levels were 0, 1-5, 6-10, 11-20, 20-30, 30-60 and 60-100 for the final TWINSPAN. Although the communities were classified based on the TWINSPAN, the indicator species of each classified vegetation association was/were identified using indicator species analysis (Dufrene & Legendre, 1997).

Plant community parameters such as plant densities, diversity, canopy and ground cover were computed (Muller-Dombois & Ellenberg, 1974; Magurran, 1988).

Tree density, browse species density, regeneration (sapling density), shrub density ground cover as well as response of chital and other wild ungulates to the different livestock grazing intensity at varying distances from three existing *Maldhari* settlement were statistically compared by analysis of variance (One way ANOVA; Zar, 1984) using SPSS- 8.0. The distance categories included proximal (0-600 m), moderate (800-1400 m) distant (1600 m to the grazing periphery of the respective Ness site) and ungrazed area (devoid of livestock). To reduce the effect of *Ness* locations (as *Maldhari* settlements are always located near perennial water courses), vegetation parameters and ungulate pellet densities were compared within each of three distance categories i.e. proximal, moderate and distant using independent sample *t* test (Zar, 1984).

6.3 Results

6.3.1: Indirect impacts of livestock grazing on food availability of chital

6.3.1.1: Grazing and trampling impact on species composition and above ground biomass

The above ground biomass in areas sympatric with livestock was used by livestock and wild ungulates; whereas, in areas devoid of livestock grazing, above ground biomass was used only by wild ungulates. The influence of small mammals e.g. rodents and invertebrates was presumed to be similar within and outside of all exclosure as mesh size was large to exclude only ungulates.

Total herbaceous biomass showed an increasing trend as livestock grazing intensity declined (Figure - 6.2). 2 way ANOVA between distance from *Ness* and exclosure (inside/outside) did not show any significant interaction (2 Way ANOVA, $F= 0.469$, $p = 0.125$), while both main effects i.e. distance from *Ness* (2 Way ANOVA, $F = 26.65$, $p \leq 0.001$) and exclosure (inside/outside) (2 Way ANOVA, $F = 21.97$, $p \leq 0.001$) were significant. The grazed and ungrazed plots i.e. outside and inside exclosures at three distance intervals,

showed similar trends in biomass production. Above ground biomass production showed an increasing trend from proximity to active *Ness* sites to the areas not grazed by livestock which suggests the long term effect of livestock grazing in reducing above ground herbaceous productivity (an increasing trend) (Figure - 6.2).

Average herbaceous production in areas used by livestock was 2257 ± 161 kg/ ha (dry weight), while in areas devoid of livestock average herbaceous production was 3341 ± 260 kg/ha (dry weight). Overall biomass removal by all ungulates was 43 % in areas used by livestock, whereas it was 21 % in devoid of livestock area. After exclusion of large herbivores, above ground biomass production showed fast recovery as it reached 67 % of above ground production in areas devoid of livestock.

For chital food, the main effects i.e. distance from *Ness* and Exclosure, could not be checked in 2 way ANOVA, as the interaction term between main effects was significant (2 Way ANOVA, $F=5.43$, $p \leq 0.05$). However, the dry biomass of herbaceous species which contributed to chital diet showed no trend with respect to distance from Ness sites. There was a difference between areas that were moderately grazed by livestock and not grazed by livestock (*Tukey HSD posthoc test*, $p=0.11$). However, those herbaceous species which contributed to the chital diet were significantly higher in the area used by livestock (*Tukey HSD posthoc test*, $p \leq 0.05$), especially in moderately grazed area (Figure - 6.3).

Figure- 6.2: Total above ground biomass production within (ungrazed) and outside of exclosure (grazed) plots in three distance from *Ness* categories in eastern Gir sanctuary. Error bars are standard errors.

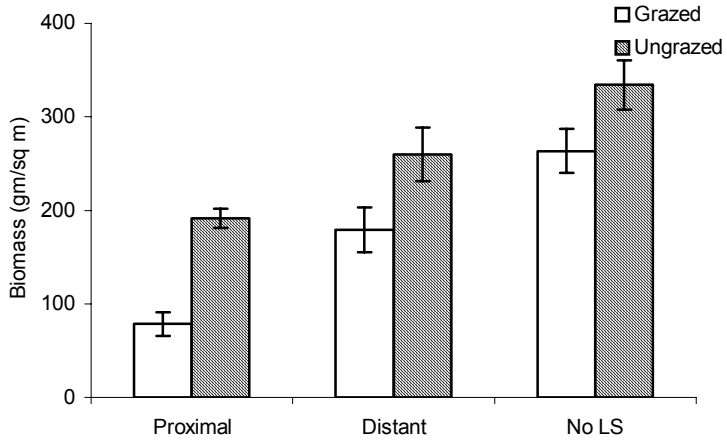
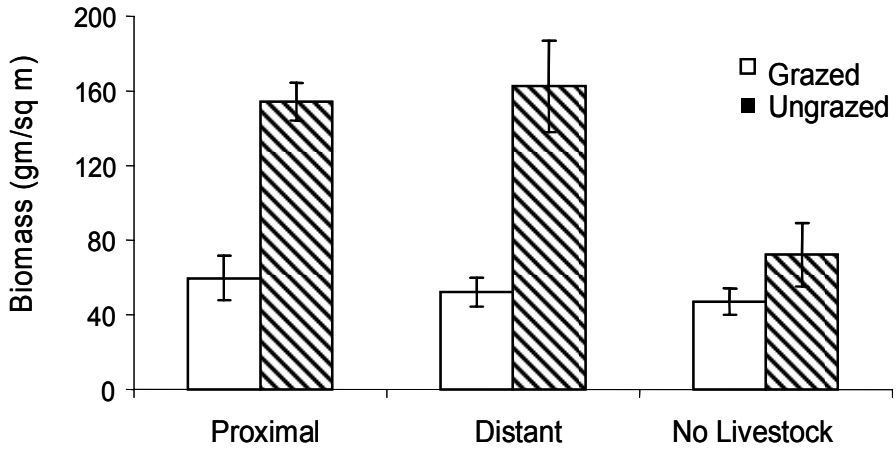
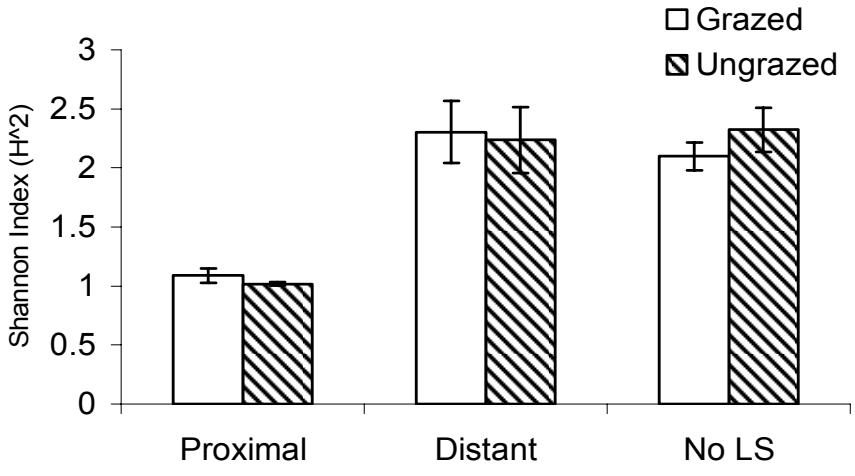


Figure- 6.3: Biomass of chital food items within (ungrazed) and outside of exclosure (grazed) plots in three distance from *Ness* categories in eastern Gir sanctuary. Error bars are standard errors.



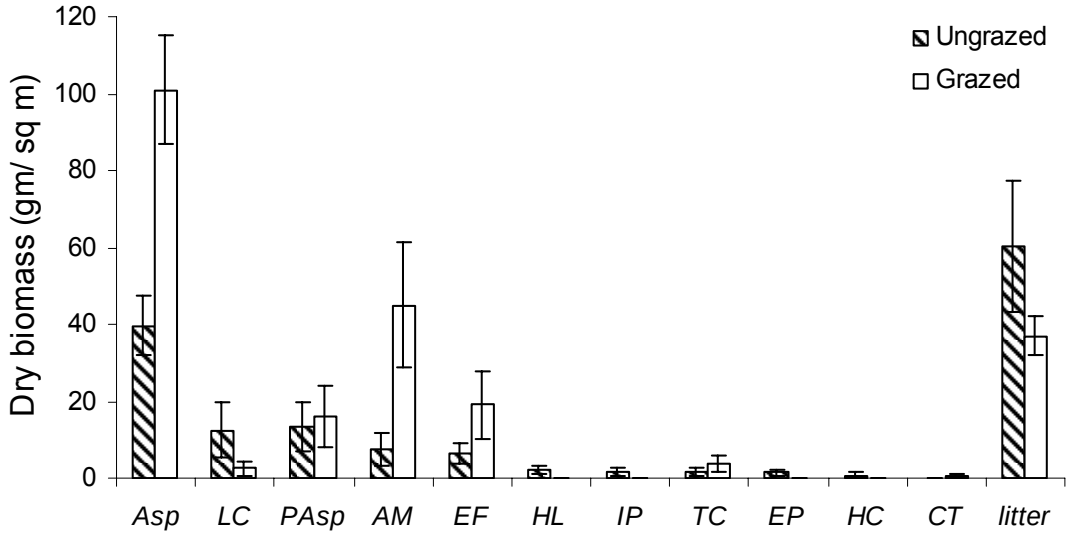
2 way ANOVA for the diversity of herbaceous species between distance from *Ness* and exclosure (inside/outside) as main effects did not show any significant interaction (2 way ANOVA, F= 0.42, p = 0.65), while the distance from *Ness* showed significant difference in herbaceous species diversity (2 way ANOVA, F = 35.37, p ≤ 0.001), nonetheless there was no difference in species diversity between distant plots i.e. moderate grazing intensity and no livestock plots i.e. devoid of livestock area (*Tukey HSD posthoc test*, p = 0.86). However, there was no significant effect of exclosure treatment on species diversity (2 ANOVA, F ≤ 0.001, p = 0.999).

Figure- 6.4: Herbaceous species diversity within (ungrazed) and outside of exclosure (grazed) plots in three distance from *Ness* categories in eastern Gir sanctuary. Error bars are standard errors.



The biomass of major graminoids between grazed and ungrazed plots i.e. outside and inside exclosures, in areas sympatric with livestock is given in figure - 6.5. The biomasses of three major grass species (frequent and abundant) are significantly high (paired *t test*: p≤ 0.05) in control plots (inside exclosures) while, litter (dead and fallen biomass) is high in sample plots (outside exclosures). Though it is not same in case of minor species (sparse and low abundant), which showed an inverse trend i.e. biomass of each species is high in the plots outside of exclosure compared to inside of exclosure plots.

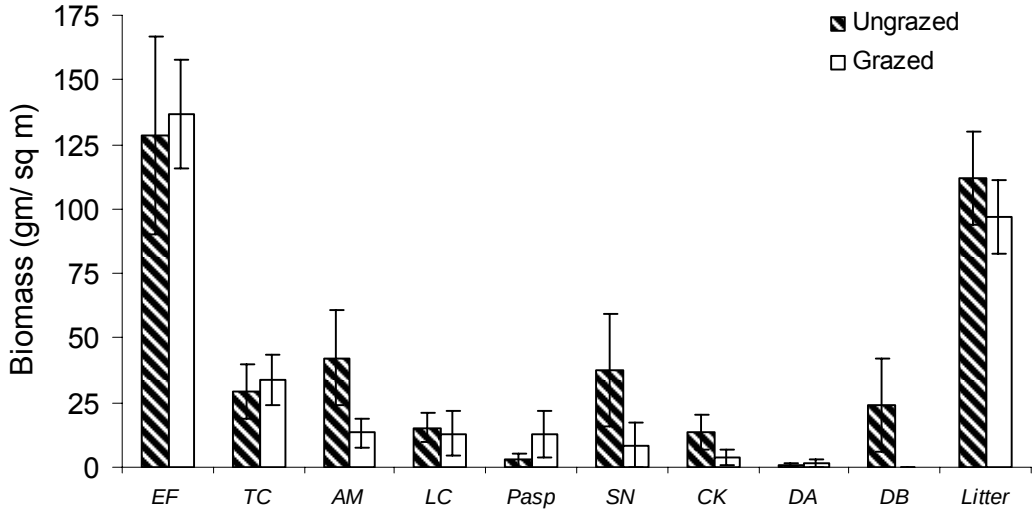
Figure- 6.5: Biomass comparison of species between grazed and ungrazed plots in livestock grazing area in eastern Gir sanctuary. Error bars are standard errors.



ASp- *Aristida sp.;* LC- *Leucas cephalotes;* PAsp- *Panicum sp.;* AM- *Apluda mutica;* EF- *Eremopogon foveolatus;* HL- *Heylandia latebrosa;* IP-*Ischamum pilosum;* TC- *Themeda cymbaria*; EP- *Eragrostis poaeoides*; HC- *Heteropogon contorius*; CT- *Cassia tora*

The comparison between biomass of each species present outside and inside exclosures in area devoid of livestock grazing is shown in the figure - 6.6. The area devoid of livestock grazing had five perennial grass species compared to only three in livestock grazed area.

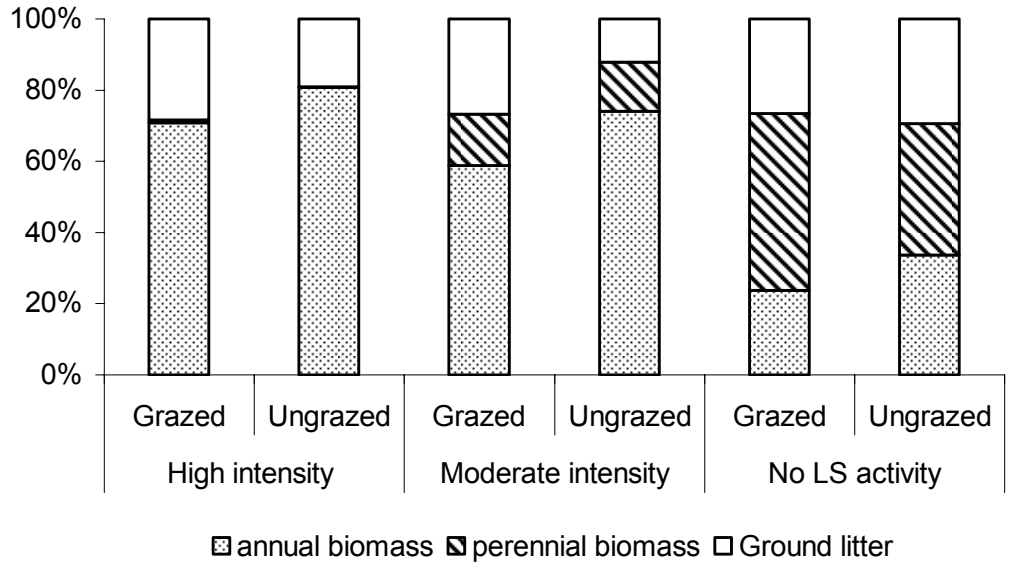
Figure- 6.6: Biomass comparison of different species between grazed and ungrazed plots in areas devoid of livestock grazing in eastern Gir sanctuary. Error bars are standard errors.



EF - *Eremopogon foveolatus*; TC – *Themeda cymbaria*; AM - *Apluda mutica;*LC - *Leucas cephalotes;* PAsp - *Panicum sp.*; SN - *Sehima nervosum*; CK - *Chionachne koenigii*; DA - *Dichanthium annulatum;* DB - *Desmostachya bipinnata*

The areas grazed by livestock had higher (74.4 %) proportion of their biomass contributed by palatable annuals compared to areas devoid of livestock (33.1 %). The maximum biomass of annuals (84.8 %) was achieved in moderately grazed areas by livestock (Figure - 6.7). Whereas in areas those were not grazed by livestock had more perennial species (5 species) which contributed very little in high intensity livestock grazing areas (3 species). Interestingly biomass of perennial species did not differ inside and outside of the exclosure, suggesting that livestock grazing resulting in mortality of perennials. Since they take longer to establish, they were not observed within the exclosures of high intensity livestock grazing.

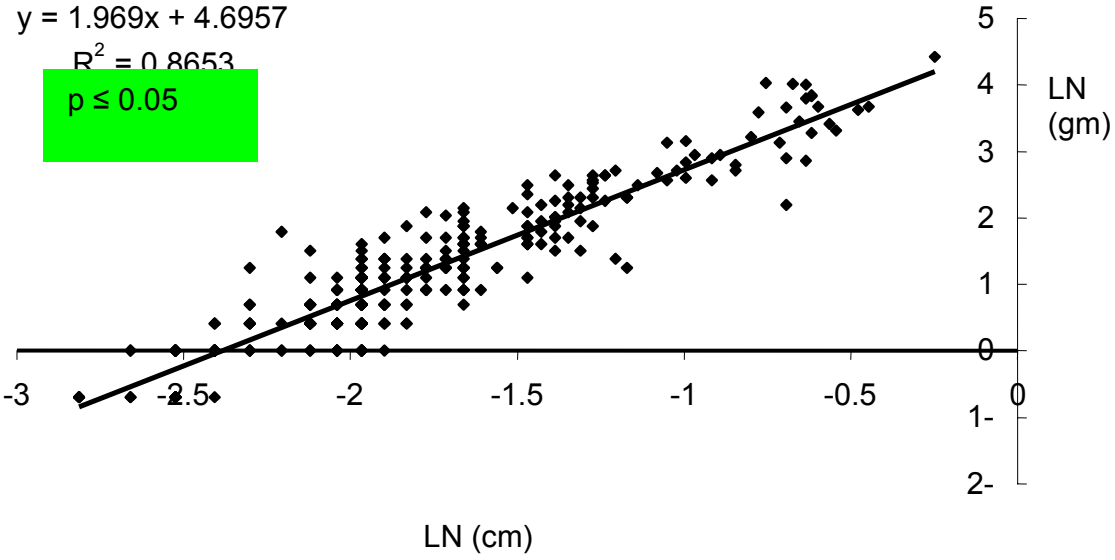
Figure- 6.7: Contribution of annual, perennial and dead biomass to total above ground herbaceous biomass within (ungrazed) and outside of exclosure (grazed) plots in different grazing intensity i.e. three distance from *Ness* categories in eastern Gir sanctuary.



6.3.1.2 Assessment of short term and long term impact of lopping and browsing on browse availability on *A. latifolia*

A regression equation was developed to predict the fresh browse growth within the reach of chital and livestock from diameter (Figure- 6.8). Paired *t* test between lopped and unlopped trees within the livestock presence area showed significantly greater browse production within the reach of chital compared to unlopped trees (Paired *t* test $t = 5.87$, $p \leq 0.01$). The more browse production over next growing season on lopped *Anogeissus latifolia* trees within the reach of ungulates could have resulted due to stimulation of lateral growth, which explains the short term impact of lopping on *Anogeissus latifolia*. Similarly, browse biomass production within reach of ungulates was more on *Anogeissus latifolia* trees irrespective of tree age and size in areas used by livestock than in areas devoid of livestock (ANCOVA, $F = 12.997$, $p \leq 0.0$, GBH as covariate: $F = 0.065$, $p \leq 0.80$). More browse production within reach of ungulates in areas used by livestock explained the effect of long term lopping on browse line height.

Figure- 6.8: Twig diameter weight regression for available browse biomass on *Anogeissus latifolia* tree in Eastern Gir sanctuary.

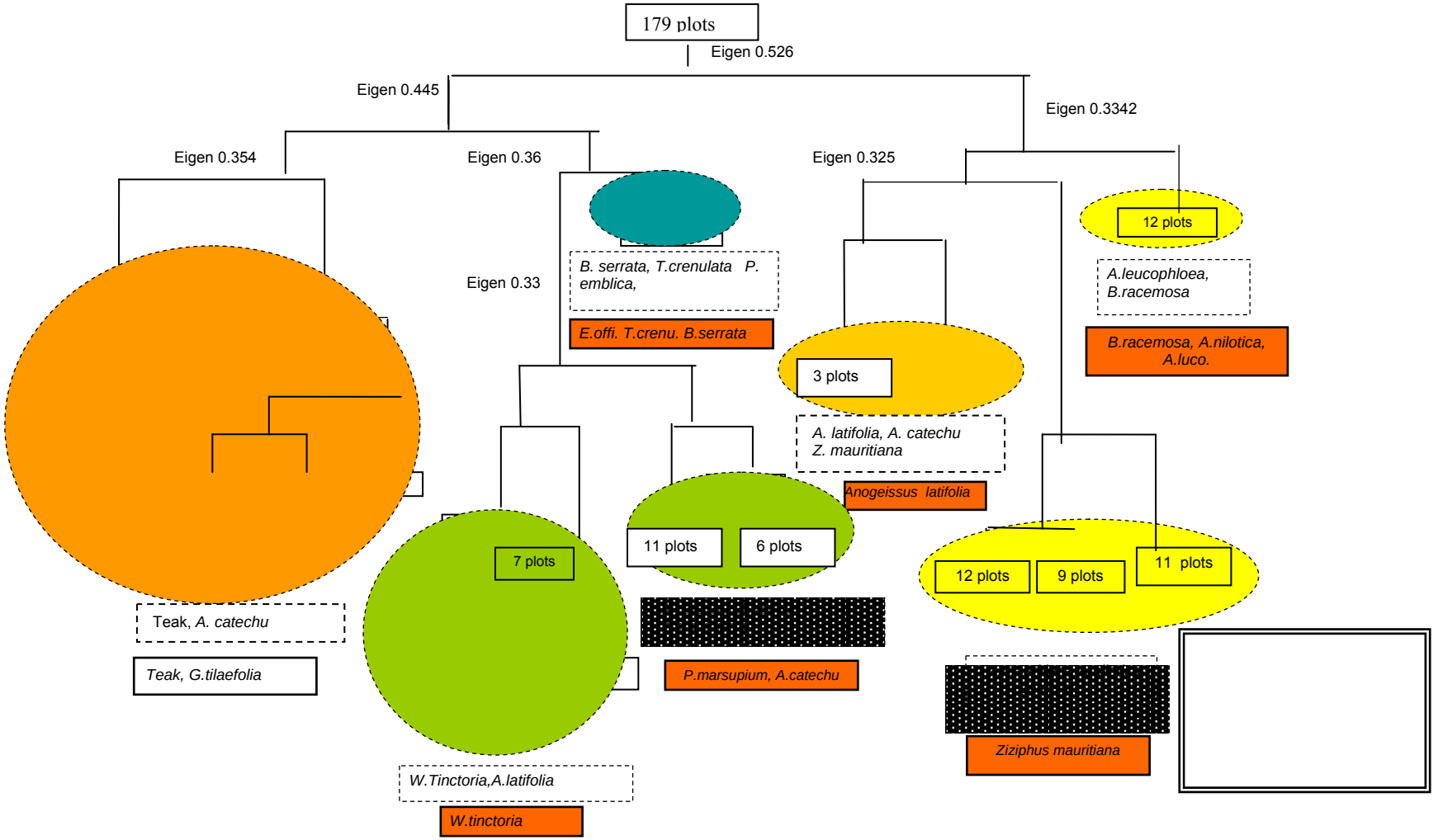


6.3.2: Indirect impact of livestock grazing on vegetation association structures

6.3.2.1: Vegetation classification

Vegetation in the intensive study area was classified into seven vegetation associations using TWINSPAN, which could also be identified in the field as well (Appendix-II). Figure - 6.9 represents this graphically with eigen values and indicator species at each division. Vegetation associations were named after abundant tree species in decreasing order. *Tectona grandis – Acacia catechu* and *Phyllanthus emblica – Terminalia crenulata – Acacia leucophloea* constitutes the dry deciduous forest. Whereas, *Acacia nilotica - Acacia leucophloea - Ziziphus mauritiana* and *Ziziphus mauritiana - Anogeissus latifolia - Acacia catechu* associations are found in Thorn forest and scrubland. The moist riverine vegetation was constituted by *Anogeissus latifolia - Acacia catechu - Terminalia crenulata* and *Acacia catechu - Anogeissus latifolia - Ziziphus mauritiana* communities. The structure and composition of each vegetation association is given in the following pages.

Figure- 6.9: Schematic representation of vegetation classification into seven communities found in the intensive study area of eastern Gir.



***Acacia nilotica - Acacia leucophloea - Ziziphus mauritiana* association (Thorn forest and scrubland)**

This association generally occurs on plains to moderate undulations and therefore coincidently occurs around *Maldhari Nesses* as all *Ness* locations are located on similar terrain near perennial water sources. The community was largely composed of thorny species. The indicator species (Indicator Species Analysis, $p \leq 0.05$) were *Acacia nilotica*, *Acacia leucophloea* and *Bauhinia racemosa* (Table - 6.1) Total tree density (D ± se) was relatively low (220.3 ± 40 trees/ ha, n= 12) compared to other vegetation associations (Table - 6.2). The most abundant tree species was *A. nilotica* (61.0 ± 15 trees /ha) followed by *A. leucophloea* (34.5 ± 10 trees /ha) and *Z. mauritiana* (31.8 ± 7.8 trees /ha) (Figure - 6.10). Undergrowth was poor in this association (201.7 ± 59.6 stems /ha). Tree regeneration was good as sapling density was 307.9 ± 85.1 saplings/ha. The saplings of *A. nilotica* (11.0 ± 8.3 %) and *Z. mauritiana* (14.9 ± 6.7 %) along with *Dichrostachys cinerea* (14.7 ± 7.5 %) found in the under growth. This community provides a mosaic of open and bushy habitat for chital and other wild ungulates, with relatively good density of browse species (191.08 ± 33.5 trees /ha). Species richness, diversity and evenness of tree, shrub and herbaceous layer is given in Table-6.4. The ground cover was 60 % which includes, 39 % dry grass, 14 % forbs, 4 % green grass and just 3 % weeds (Table - 6.3). Among grasses, annuals like *Apluda mutica* and *Panicum sp* contributed largely to the ground cover (Figure - 6.10).

Table- 6.1: Indicator species for different plant communities in eastern Gir sanctuary.

No.	Plant Communities	Indicator Species	Value (IV)	p *
Association - 1	*Acacia nilotica – Acacia leucophloea – Ziziphus mauritiana*	*Bauhinia racemosa*	13.8	*
		Acacia nilotica	38.0	* * *
		Acacia leucophloea	29.1	* * *
Association - 2	*Tectona grandis – Acacia catechu*	*Tectona grandis*	90.6	* * *
		Grewia tilaefolia	12.6	*
Association - 3	*Phyllanthus emblica – Terminalia crenulata – Acacia leucophloea*	*Phyllanthus emblica*	51.4	* * *
		Terminalia crenulata	31.6	* * *
		Boswelia serrata	29.2	* * *
Association - 4	*Ziziphus mauritiana – Anogeissus latifolia – Acacia catechu*	*Anogeissus latifolia*	34.3	* * *
Association - 5	*Ziziphus mauritiana – Acacia nilotica – Acacia leucophloea*	*Ziziphus mauritiana*	44.5	* * *
Association - 6	*Acacia catechu – Anogeissus latifolia – Lannea coromondelica*	*Pterocarpus marsupium*	17.3	* *
		Acacia catechu	43.9	* * *
Association - 7	*Anogeissus latifolia – Acacia catechu – Terminalia crenulata*	*Wrightia tinctoria*	35.8	* * *

**** - p ≤ 0.05***

***** - p ≤ 0.01***

******- p ≤ 0.001***

Table- 6.2: Comparative account of the densities of all tree species, browse trees, saplings as well as shrubs in different plant communities of intensive study area of eastern Gir sanctuary.

No.	Plant Communities	Canopy	Tree (Mean ±SE)					Shrub (Mean ±SE)	
			Total Density (per ha)	Browse Species Density (per ha)	Saplings Density (per ha)	GBH (cm)	Height (m)	Density (per ha)	Height (m)
1	*Acacia nilotica – Acacia leucophloea – Ziziphus mauritiana*	**31.9** (7.4)	**220.3** (40.1)	**191.1** (33.5)	**307.9** (85.1)	**53.0** (3.37)	**5.88** (0.82)	**201.7** (59.6)	**1.45** (0.15)
2	*Tectona grandis – Acacia catechu*	**76.7** (1.8)	**318.5** (19.8)	**134.9** (13.9)	**550.8** (93.3)	**55.7** (1.72)	**7.44** (0.28)	**415.9** (94.7)	**1.60** (0.08)
3	*Phylanthus emblica – Terminalia crenulata – Acacia leucophloea*	**25.0** (1.7)	**248.9** (38.8)	**222.9** (39.8)	**335.8** (110.4)	**52.5** (2.45)	**5.86** (0.36)	**231.6** (85.6)	**1.66** (0.10)
4	*Ziziphus mauritiana – Acacia latifolia – Acacia catechu*	**35.3** (4.2)	**254.8** (35.8)	**248.4** (32.6)	**501.1** (98.3)	**49.7** (3.27)	**5.33** (0.17)	**382.2** (73.6)	**1.13** (0.07)
5	*Ziziphus mauritiana – Acacia nilotica – Acacia leucophloea*	**32.1** (3.0)	**212.9** (20.8)	**201.0** (18.6)	**298.6** (83.0)	**52.2** (2.43)	**4.84** (0.24)	**254.8** (63.9)	**1.28** (0.08)
6	*Acacia catechu – Anogeissus latifolia – Lannea coromondelica*	**40.0** (3.7)	**270.1** (27.8)	**222.9** (23.3)	**254.8** (61.6)	**54.8** (3.30)	**6.24** (0.68)	**283.1** (109.7)	**1.54** (0.12)
7	*Anogeissus latifolia – Acacia catechu – Terminalia crenulata*	**48.6** (3.4)	**374.6** (21.9)	**345.5** (19.5)	**612.0** (115.4)	**54.4** (1.98)	**6.00** (0.17)	**794.8** (224.9)	**1.46** (0.05)

Table- 6.3: comparative account of structure and composition of different plant communities in eastern Gir sanctuary.

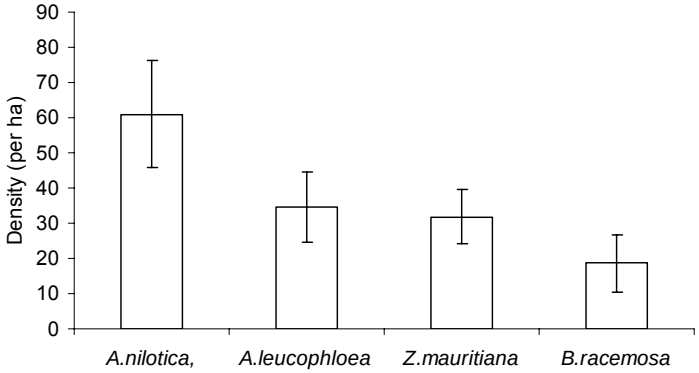
No.	Plant communites	leaf litter %	Ground cover composition (Mean± SE)				
			Green grass %	Dry grass %	Forbs %	Unpalatable %	Bare ground %
1	*Acacia nilotica – Acacia leucophloea – Ziziphus mauritiana*	**34.2** (10.8)	**2.9** (1.9)	**42.9** (9.3)	**12.8** (3.9)	**2.5** (1.6)	**38.9** (9.1)
2	*Tectona grandis – Acacia catechu*	**40.2** (5.1)	**3.4** (0.9)	**33.7** (5.0)	**14.2** (2.1)	**3.1** (1.0)	**45.6** (5.5)
3	*Phyllanthus emblica – Terminalia crenulata – Acacia leucophloea*	**21.8** (7.1)	**7.7** (3.9)	**48.2** (7.6)	**17.7** (4.3)	**4.6** (2.0)	**21.8** (7.6)
4	*Ziziphus mauritiana – Acacia latifolia – Acacia catechu*	**22.7** (4.4)	**1.2** (0.7)	**30.1** (7.1)	**20.8** (4.5)	**2.9** (1.1)	**45.0** (8.0)
5	*Ziziphus mauritiana – Acacia nilotica – Acacia leucophloea*	**22.7** (3.6)	**5.3** (2.5)	**31.0** (4.1)	**14.9** (2.5)	**7.8** (1.7)	**40.9** (5.1)
6	*Acacia catechu – Anogeissus latifolia – Lannea coromondelica*	**34.6** (5.9)	**3.8** (1.5)	**39.3** (5.9)	**13.9** (2.5)	**2.9** (0.7)	**40.2** (6.5)
7	*Anogeissus latifolia – Acacia catechu – Terminalia crenulata*	**38.4** (4.5)	**1.6** (0.7)	**38.3** (4.5)	**26.1** (3.3)	**1.5** (0.4)	**32.5** (4.2)

Table- 6.4: Comparative account of richness S, diversity H' and evenness E for tree, shrub and herbaceous layers of different plant communities in eastern Gir sanctuary.

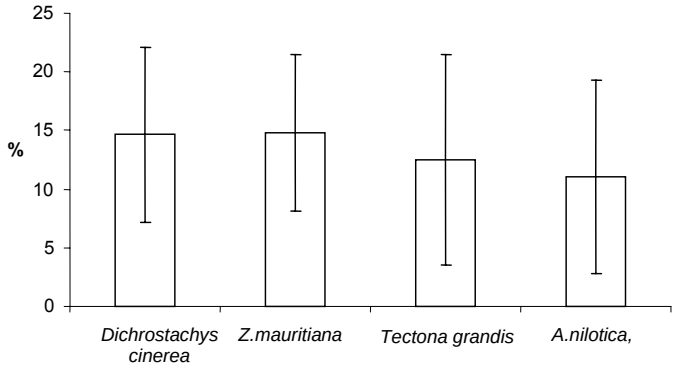
No.	Vegetation association	Tree Layer			Shrub Layer			Herb Layer		
		Richness S	**Diversity H'** (Shannon Index)	**Evenness E**	**Richness S**	**Diversity H'** (Shannon Index)	**Evenness E**	**Richness S**	**Diversity H'** (Shannon Index)	**Evenness E**
1	*Acacia nilotica – Acacia leucophloea – Ziziphus mauritiana*	**4.17** (0.79)	**1.15** (0.19)	**0.94** (0.02)	**2.50** (0.54)	**0.76** (0.18)	**0.94** (0.02)	**4.00** (0.51)	**1.04** (0.07)	**0.73** (0.03)
2	*Tectona grandis – Acacia catechu*	**4.53** (0.29)	**1.22** (0.08)	**0.82** (0.03)	**3.44** (0.41)	**1.00** (0.11)	**0.90** (0.02)	**3.71** (0.17)	**0.97** (0.05)	**0.76** (0.03)
3	*Phyllanthus emblica – Terminalia crenulata – Acacia leucophloea*	**4.64** (0.66)	**1.32** (0.13)	**0.93** (0.02)	**2.64** (0.72)	**0.89** (0.20)	**0.93** (0.03)	**4.45** (0.49)	**1.12** (0.07)	**0.82** (0.04)
4	*Ziziphus mauritiana – Acacia latifolia – Acacia catechu*	**4.27** (0.37)	**1.27** (0.07)	**0.92** (0.02)	**3.07** (0.28)	**0.93** (0.07)	**0.88** (0.02)	**4.67** (0.43)	**1.10** (0.11)	**0.77** (0.03)
5	*Ziziphus mauritiana – Acacia nilotica – Acacia leucophloea*	**2.88** (0.22)	**0.84** (0.08)	**0.90** (0.02)	**2.03** (0.39)	**0.91** (0.10)	**0.91** (0.02)	**4.59** (0.32)	**1.17** (0.06)	**0.80** (0.02)
6	*Acacia catechu – Anogeissus latifolia – Lannea coromondelica*	**4.56** (0.47)	**1.23** (0.10)	**0.89** (0.02)	**1.81** (0.32)	**0.68** (0.10)	**0.93** (0.02)	**4.00** (0.38)	**1.06** (0.09)	**0.79** (0.03)
7	*Anogeissus latifolia – Acacia catechu – Terminalia crenulata*	**5.61** (0.31)	**1.48** (0.06)	**0.89** (0.01)	**4.24** (0.94)	**1.02** (0.09)	**0.85** (0.03)	**3.72** (0.23)	**0.89** (0.06)	**0.73** (0.03)

Figure- 6.10: Vegetation structure and composition of *Acacia nilotica - Acacia leucophloea – Ziziphus mauritiana* association in eastern Gir sanctuary.

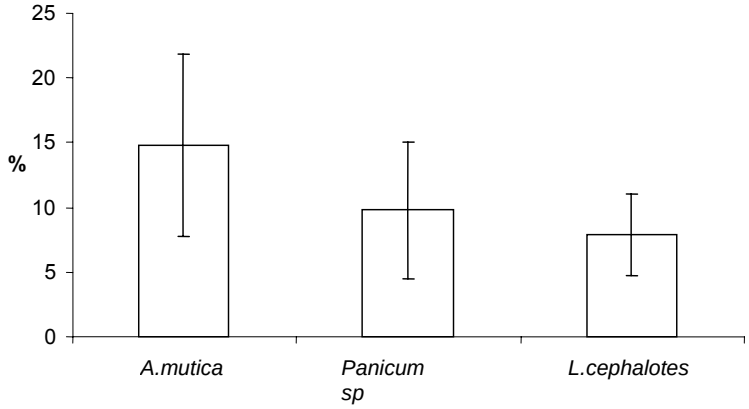
A) Density of major tree species



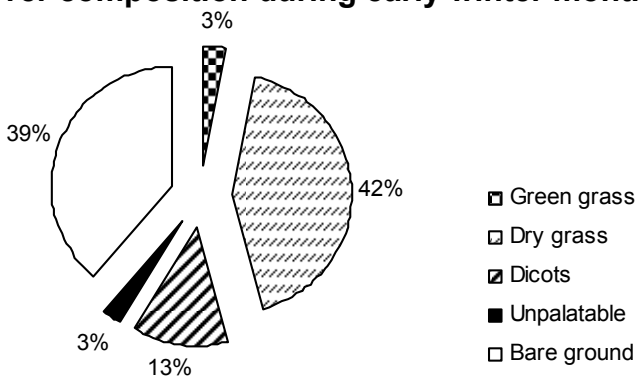
B) Percent contribution of major plant species to total shrub abundance



C) Percent contribution of major grass species to total ground cover



D) Ground cover composition during early winter months



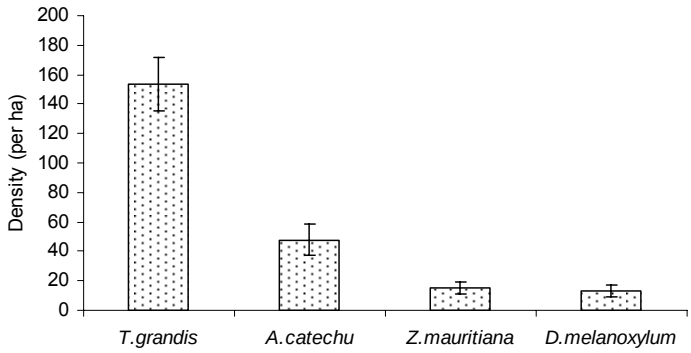
***Tectona grandis - Acacia catechu* association**

(Teak dominated woodland)

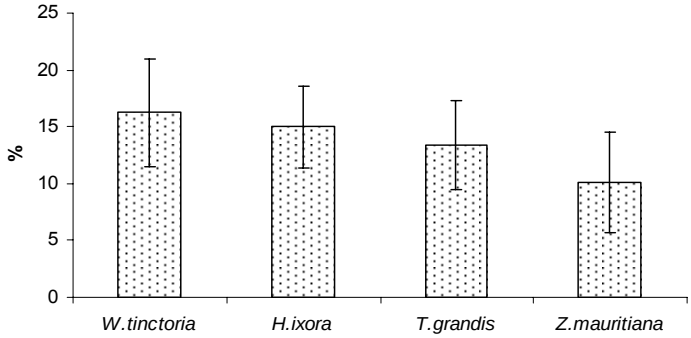
This vegetation association occurs on plains to moderate slopes, mostly in areas devoid of livestock adjacent to the National Park area. The community represents dense woodland (318.5 ± 19.8 trees /ha) (Table - 6.2). The upper canopy consisted of *Tectona grandis* (153.6 ± 18.6 trees /ha) with scattered *Diospyros melanoxylon* 13.1 ± 4.1 trees /ha), while sparse understory species includes *Acacia catechu* (47.8 ± 10.6 trees /ha) and *Z. mauritiana* (14.99 ± 4.3 trees /ha) (Figure - 6.11). The dense undergrowth (415.9 ± 95.8 stems /ha) was composed of a number of shrub species and saplings. The most abundant shrub was *Helicteres isora* (15 ± 3.6 %), while among tree saplings, *Wrightia tinctoria* (16.3 ± 4.7 %), *Tectona grandis* (13.4 ± 3.9 %) and *Z. mauritiana* (10.1 ± 4.4 %) were the most abundant. The indicator species (Indicator Species Analysis, $p \leq 0.05$) for this community were *T. grandis* and *Grewia tilaefolia* (Table - 6.1). The ground during early winter months was largely covered with fallen leaves of deciduous trees (40.2 ± 5.1 %) (Table - 6.3). Apart from leaf litter, ground was 45.6 ± 5.5 % barren and rest was covered with dry grass (33.7 ± 5.0 %), forbs (14.2 ± 2.1 %), green grass (3.4 ± 0.97 %) and unpalatable weeds (3.1 ± 1.0 %) (Figure - 6.11).

Figure- 6.11: Vegetation structure and composition of *Tectona grandis* – *Acacia catechu* association in eastern Gir sanctuary.

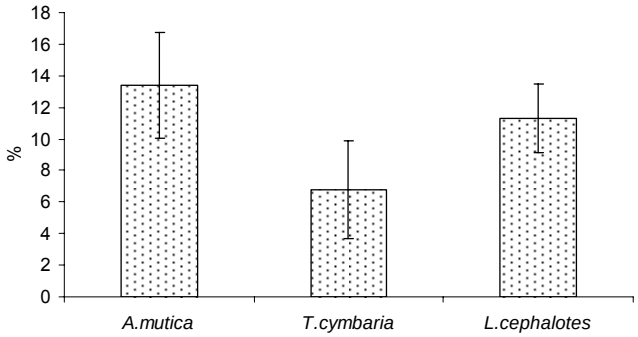
A) Density of major tree species



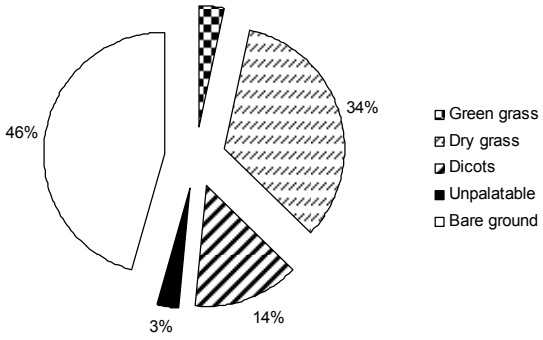
B) Percent contribution of major plant species to total shrub abundance



C) Percent contribution of major grass species to total ground cover



D) Ground cover composition during early winter months



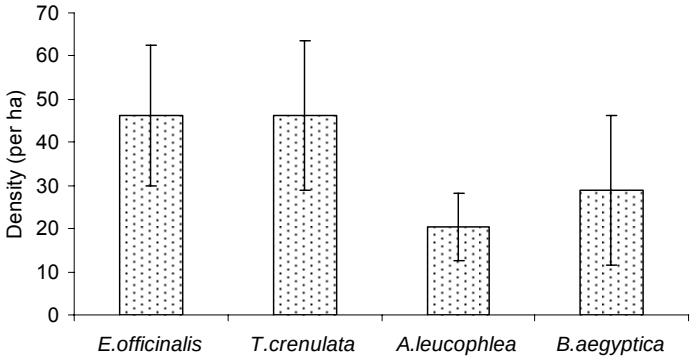
Phylanthus emblica – Terminalia crenulata – Acacia leucophloea **association**

(Terminalia – Acacia* woodland*)

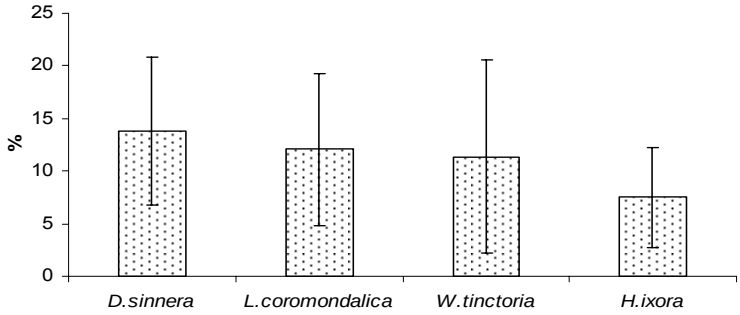
This association occurred on drier hilly terrain with moderate to steep slopes of eastern Gir sanctuary. *T. crenulata* formed the upper canopy. In western Gir, other associated species of *T. crenulata* get replaced by *T. grandis.* This vegetation type is interspersed with open grassy patches on hill tops. Indicator species for this vegetation types were *P. emblica, Boswelia serreta* and *T. crenulata* ($p \leq 0.05$) (Table - 6.1). Total tree density in this vegetation association was 248.9 ± 38.8 trees /ha. The most abundant tree species were *P. emblica* (46.3 ± 16.3 trees /ha) and *T. crenulata* (46.3 ± 17.4 trees /ha) (Figure - 6.12). The undergrowth was relatively poor (231.6 ± 85.6 shrubs /ha), which included *Dichrostachys cinerea* (13.8 ± 7.1 shrubs /ha), *Wrightia tinctoria* (11.4 ± 9.2 shrubs/ha) and saplings of *Lannea coromondelica* (12.1 ± 7.3 shrubs/ha). The ground cover included 48.2 % dry grass and 7.7 % green grass. This vegetation association had relatively better ground cover as barren ground was just 21.9 % while unpalatable weeds contributed less than 5 % (Table - 6.3). Among grasses, *A. mutica* contributed 31.7 (± 7.6) % followed by *Eremopogon foveolatus* (6.5 ± 2.3 %) (Figure - 6.12).

Figure- 6.12: Vegetation structure and composition of *Phyllanthus emblica – Terminalia crenulata – Acacia leucophloea* association in eastern Gir sanctuary.

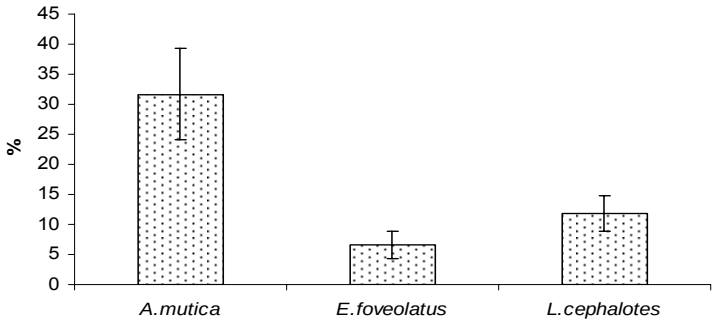
A) Density of major tree species



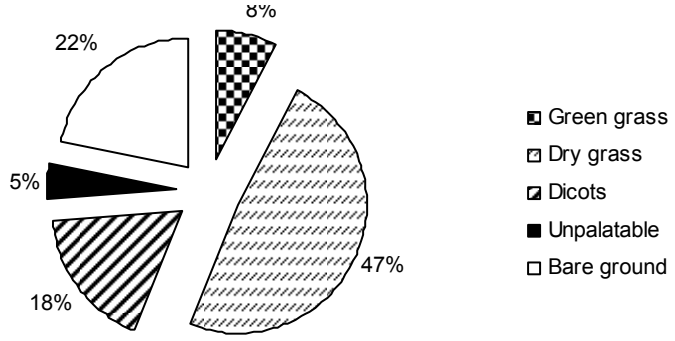
B) Percent contribution of major plant species to total shrub abundance



C) Percent contribution of major grass species to total ground cover



D) Ground cover composition during early winter months

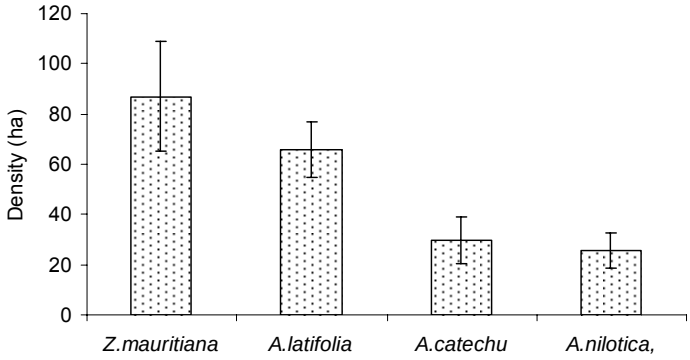


***Ziziphus mauritiana – Anogeissus latifolia – Acacia catechu* association (Mixed thorn forest)**

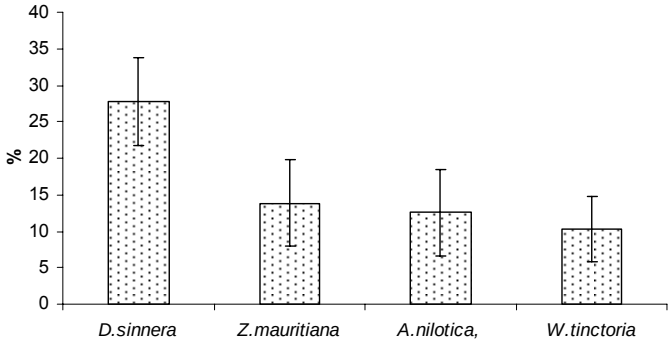
This community formed open woodland with *Z. mauritiana* and *A. latifolia* as upper canopy species. The association occurred on slight to moderately undulating terrain. The tree density was 254.8 (± 35.8) trees/ha (Table - 6.2). The most abundant tree species was *Z. mauritiana* (87.0 ± 21.9 trees/ha), followed by *A. latifolia* (65.8 ± 10.9 trees/ha) (Figure - 6.13). The indicator species for this association was *A. latifolia* ($p \leq 0.05$). Total density of shrubs and sapling was 382.2 (± 73.6) stems/ha (Table - 6.2). The undergrowth was composed of *Dichrostachys cinerea* (27.7 ± 6.1 %) and *Wrightia tinctoria* (10.2 ± 4.4 %) as well as saplings of *Z. mauritiana* (13.9 ± 6.0 %) and *Acacia nilotica* (12.6 5.9 %). This vegetation type supports a good density of browse species (248.4 ± 32.6 trees/ha). The ground cover was poor compared to other vegetation types (45 % barren ground) (Table - 6.3). However, grass and forbs diversity was good, with little unpalatable ground cover (2.9 ± 1.1 %) during early winter months. Among grasses, annual species like *A. mutica* (9.4 ± 4.3 %) and *Panicum sp.* (6.5 ± 3.8 %) predominantly contribute to the overall ground cover (Figure - 6.13).

Figure- 6.13: Vegetation structure and composition of *Ziziphus mauritiana – Anogeissus latifolia – Acacia catechu* association in eastern Gir sanctuary.

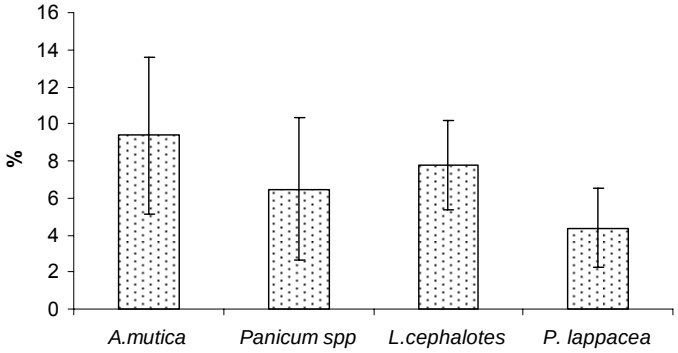
A) Density of major tree species



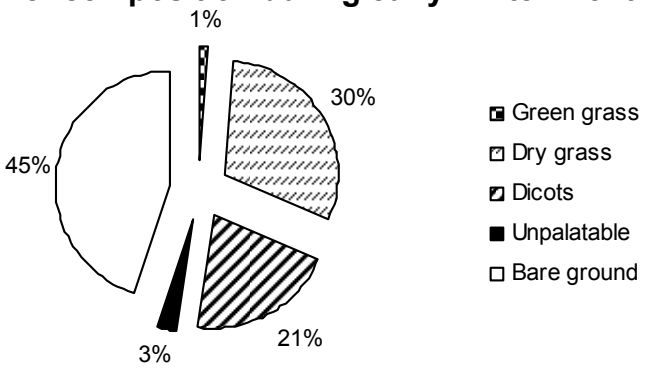
B) Percent contribution of major plant species to total shrub abundance



C) Percent contribution of major grass species to total ground cover



D) Ground cover composition during early winter months

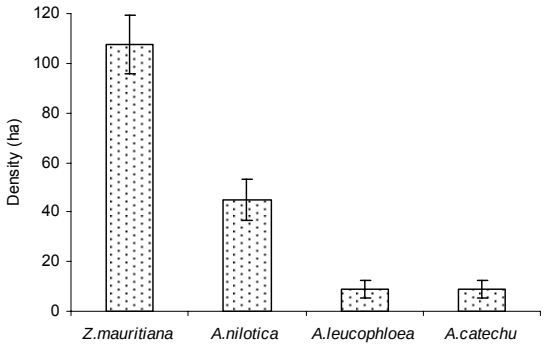


Ziziphus mauritiana – Acacia nilotica – Acacia leucophloea

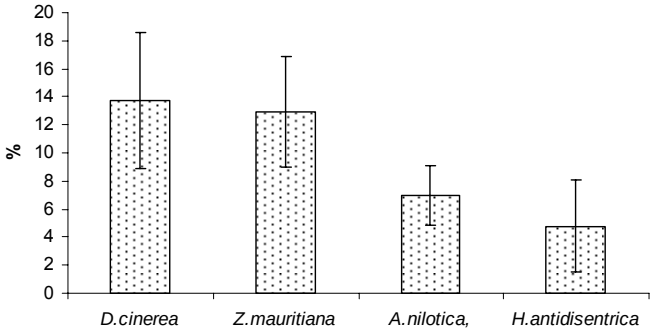
This association largely represents scrubland with all thorny species. It occurs on flat to gentle undulating terrain. The tree density was 212.9 (± 20.8) trees/ha (Table - 6.2). The upper canopy is scanty, represented by *Z. mauritiana*. Most of the trees were dwarf with an average height 4.8 (± 1.3) m. The undergrowth was dense and bushy (254.8 ± 64.0 stems/ha), mostly composed of *Dichrostachys cinerea* (13.8 ± 4.8 %) and bushy *Z. mauritiana* (13.0 ± 3.9 %). The indicator species for this community was *Z. mauritiana* ($p \leq 0.05$). The most abundant species for this community was *Z. mauritiana* (107.5 ± 11.7 stems/ha), followed by scattered *A. nilotica* (44.8 ± 8.3 stems/ha). This community forms dense thicket interspersed with open patches of short grasses. Herbaceous cover on ground was 50.1 5.1 % (Table - 6.3). This vegetation association had poor tree and shrub diversity and richness but better herbaceous diversity and richness compared to other vegetation associations (Table - 6.4). The ground cover was composed of dry and mostly annual short grasses viz. *A. mutica* (7.1 ± 2.3 %), *Panicum sp.* (4.4 ± 2.0 %) with patchily distributed perennial grasses i.e. *Heteropogon triticeous* (4.3 ± 2.3). The contribution of unpalatable species to the total ground cover was comparatively higher in this community (*Cassia tora*: 4.63 ± 1.37 %) (Figure - 6.14).

Figure- 6.14: Vegetation structure and composition of *Ziziphus mauritiana – Acacia nilotica – Acacia leucophloea* association in eastern Gir sanctuary.

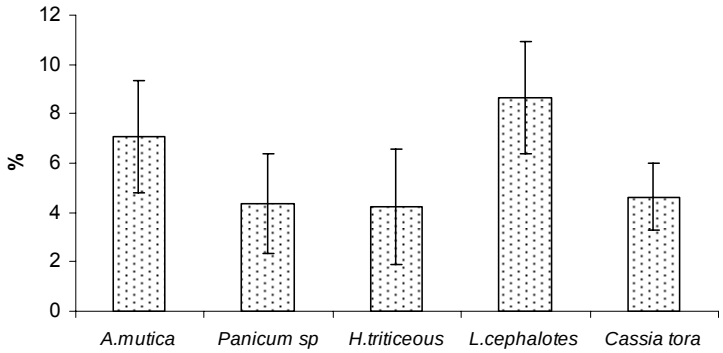
A) Density of major tree species



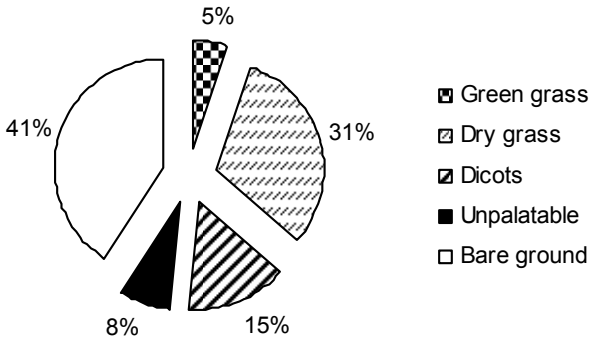
B) Percent contribution of major plant species to total shrub abundance



C) Percent contribution of major grass species to total ground cover



D) Ground cover composition during early winter months

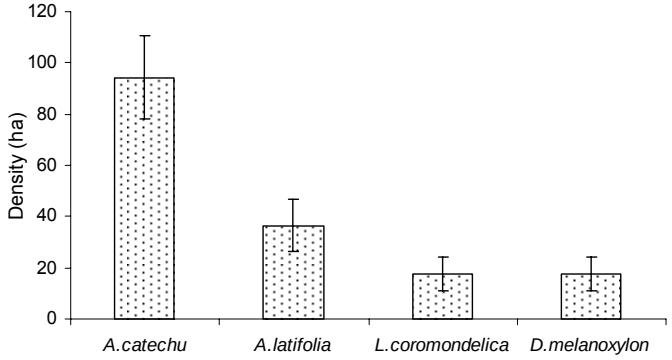


Acacia catechu – Anogeissus latifolia – Lannea coromandelica **association (Moist mixed vegetation)**

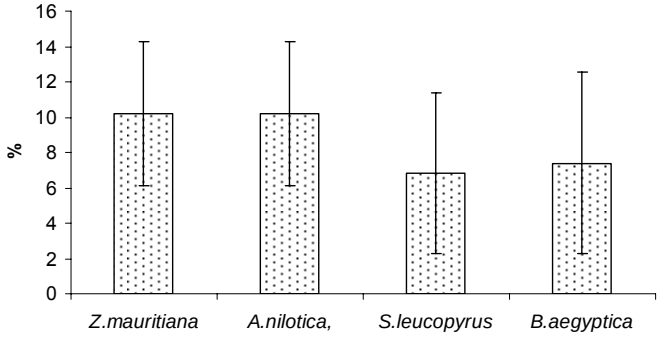
This community occurs along the water courses, depressions and valleys. The association included all thorny species. Total tree density was 270 ± 27.8 trees/ ha (Table - 6.2). The most abundant tree species was *A. catechu* (94.4 ± 16.3 trees/ ha) followed by *A. latifolia* (36.6 ± 10.2 trees/ha) (Figure - 6.15). The indicator species for this vegetation association were *Pterocarpus marsupium* and *Acacia catechu* ($p \leq 0.01$) (Table - 6.1). The upper story was composed of *A. catechu*, *A. latifolia*, *Lannea coromandelica* and *Diospyros melanoxylon* while, the dense patchy undergrowth (283.1 ± 109.7 stems/ha) included *Z. mauritiana* (10.9 ± 4.1 %); *A. nilotica* (10.9 ± 4.1 %); *Securingea leucopyrus* (6.9 ± 4.5 %); and *Balanites aegyptica* (6.9 ± 4.5 %). Tree species richness (4.56 ± 0.47) and diversity (1.23 ± 0.1) were good but shrub and herbaceous species richness (1.81 ± 03 & 4.0 ± 0.4 respectively) and diversity (0.68 ± 0.1 & 1.06 ± 0.1, respectively) were comparatively poor (Table - 6.4). The ground cover included 40.2 % barren ground, 39.3 % dry annual grasses and 13.9 % forbs (Table - 6.4). Among grasses, *A. mutica* (16.4 ± 4.4 %) was the most abundant grass followed by *Themeda cymbaria* (8.3 ± 3.4 %) and *Aristida sp* (6.0 ± 3.7 %) (Figure - 6.15).

Figure- 6.15: Vegetation structure and composition of *Acacia catechu – Anogeissus latifolia – Lannea coromondelica* association in eastern Gir sanctuary.

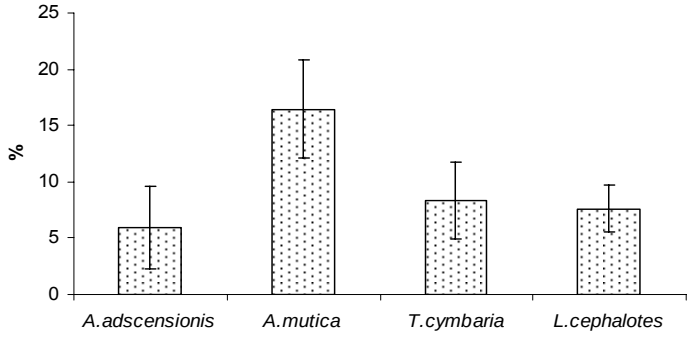
A) Density of major tree species



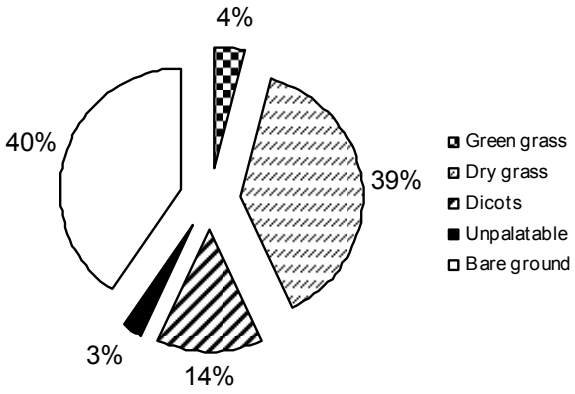
B) Percent contribution of major plant species to total shrub abundance



C) Percent contribution of major grass species to total ground cover



D) Ground cover composition during early winter months

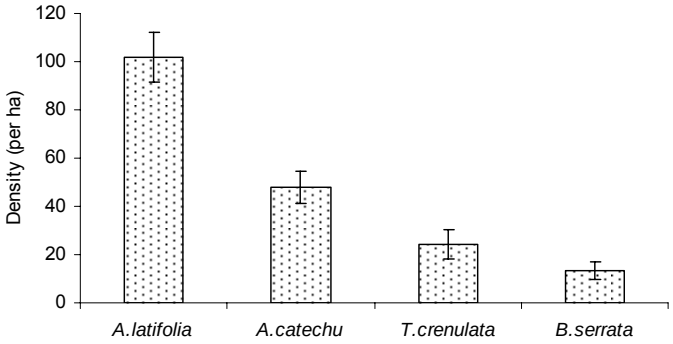


***Anogeissus latifolia – Acacia catechu – Terminalia crenulata* association (Moist mixed vegetation)**

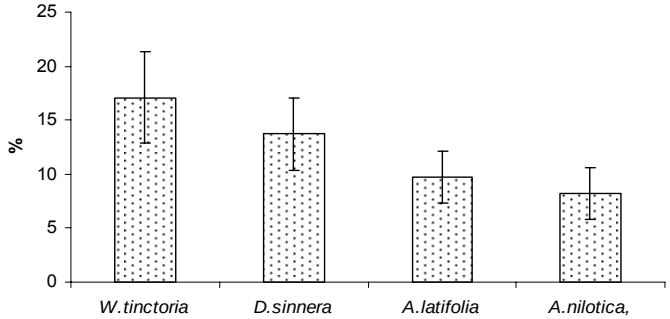
The community occurred on the gentle to moderate slopes along the drainages. The association formed a dense moist mixed habitat with 374.5 ± 21.9 trees/ ha (Table - 6.2). The most abundant tree was *A. latifolia* (101.8 ± 10.2) followed by *A. catechu* (47.8 ± 6.8 trees/ha) and *T. crenulata* (24.2 ± 6.0 trees/ha) (Figure - 6.16). The upper story was formed by *T. crenulata* and *A. latifolia*. The indicator species for this vegetation association was *W. tinctoria* ($p \leq 0.001$). The undergrowth was very dense (794.8 ± 225.1 stems/ha). The undergrowth included bushy *W. tinctoria* (17.1 ± 4.2 %) and *D. cinerea* (8.3 ± 2.4 %) (Figure - 6.15). The average height of the tree layer was higher (6.0 ± 1.2 m) than other vegetation communities (Table - 6.2). Tree and shrub species richness (5.6 ± 0.3 & 4.24 ± 0.9, respectively) and diversity (1.48 ± 0.1 & 1.02 ± 0.1, respectively) were maximum compared to other vegetation associations (Table - 6.4). The ground cover included 38.3 ± 4.5 % annual grasses and 26.1 ± 3.3 % (Table - 6.3). *Apluda mutica* (19.3 ± 3.3 %) and *Aristida sp.* were the abundant grasses while, *Leucas cephalotes* (11.6 ± 2.0 %) was the most abundant forbs followed by *Sida cordata* (4.3 ± 1.4 %). The contribution of unpalatable species was very little (1.5 ± 0.4 %) (Figure - 6.16).

Figure- 6.16: Vegetation structure and composition of *Anogeissus latifolia – Acacia catechu – Terminalia crenulata* association in eastern Gir sanctuary.

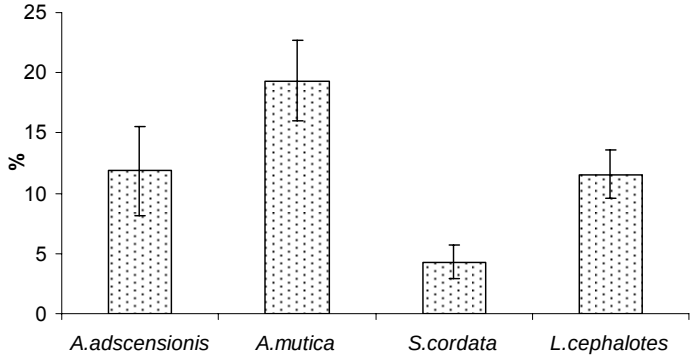
A) Density of major tree species



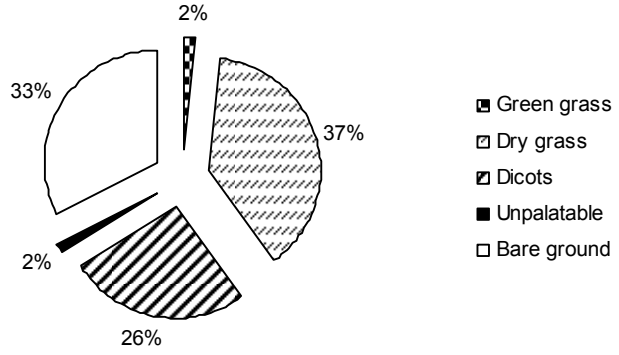
B) Percent contribution of major plant species to total shrub abundance



C) Percent contribution of major grass species to total ground cover



D) Ground cover composition during early winter months



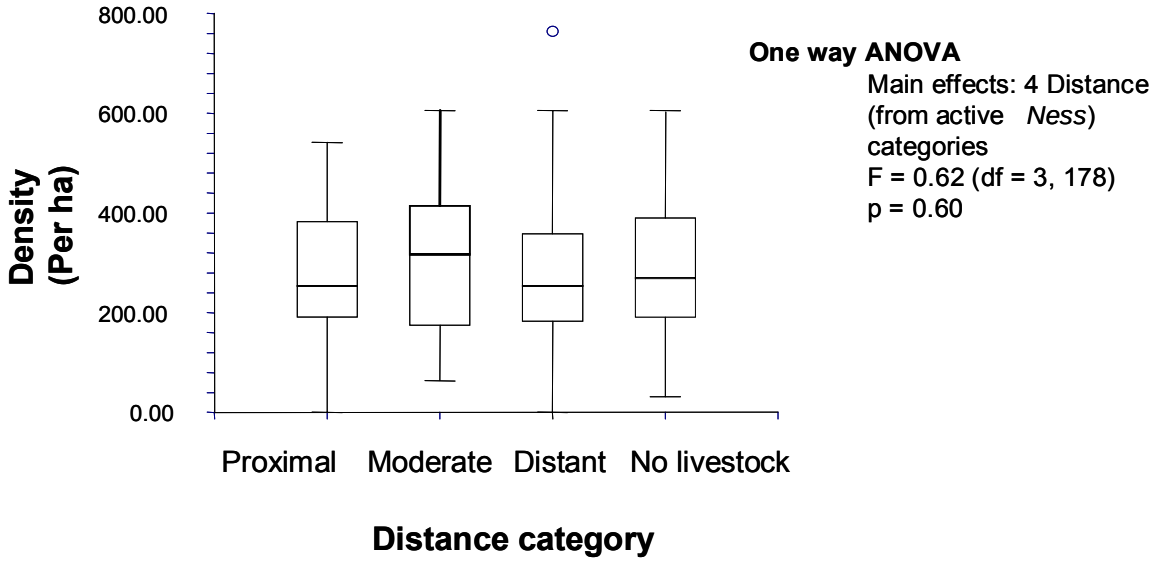
6.3.2.2 Assessment of livestock grazing impact on tree layer

Maximum tree density was found in *A. latifolia – A. catechu – T. crenulata* association which represents the moist mixed riverine habitat while minimum tree density was in *Z. mauritiana – A. nilotica – A. leucophloea* (*Acacia – Ziziphus* scrubland habitat) association (Table - 6.2). Maximum sapling density was in *A. latifolia – A. catechu – T. crenulata* association while minimum sapling density was in *A. catechu – A. latifolia – L. coromondelica* association. The density of browse tree species was maximum in *A. latifolia – A. catechu – T. crenulata* while lowest browse tree species density was in *A. nilotica – A. leucophloea – Z. mauritiana* association (Table - 6.2). A list of browse trees available in the intensive study site of eastern Gir sanctuary is given in Appendix- III.

a) Total tree density

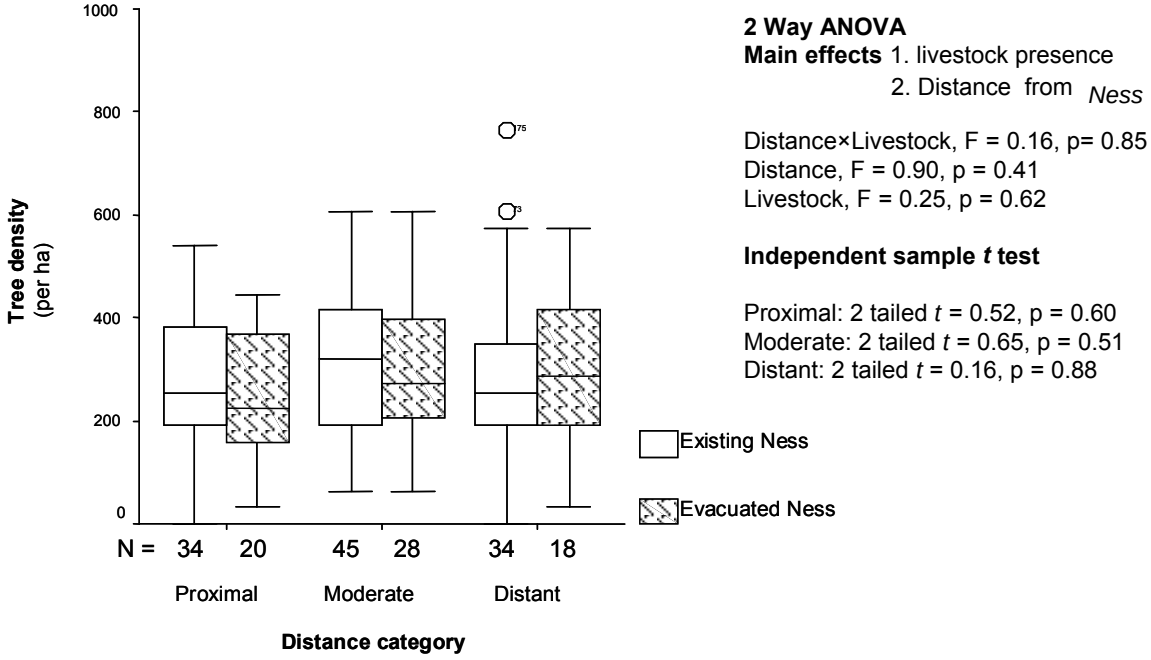
Comparison of overall tree densities at varying intensity of livestock grazing i.e. four distance categories from the peripheries of active *Maldhari Ness* sites, revealed no difference in tree densities (One way ANOVA, F = 0.62, p = 0.60) (Figure- 6.17).

Figure- 6.17: Box & Whisker plot of total tree density at different distance categories from active *Maldhari Ness* sites in eastern Gir sanctuary.



No significant effect of livestock presence (F = 0.25, p = 0.62) or distance from ness (F = 0.90, p = 0.41) on tree density were confirmed by two-way ANOVA. Tree density was also not different within the same grazing distances of grazed i.e. active *Ness* sites and ungrazed i.e. evacuated *Ness* sites (Independent sample *t* test, proximal: 2 tailed *t* = 0.52, p = 0.60; moderate: 2 tailed *t* = 0.65, p = 0.51; distant: 2 tailed *t* = 0.16, p = 0.88) (Figure - 6.18).

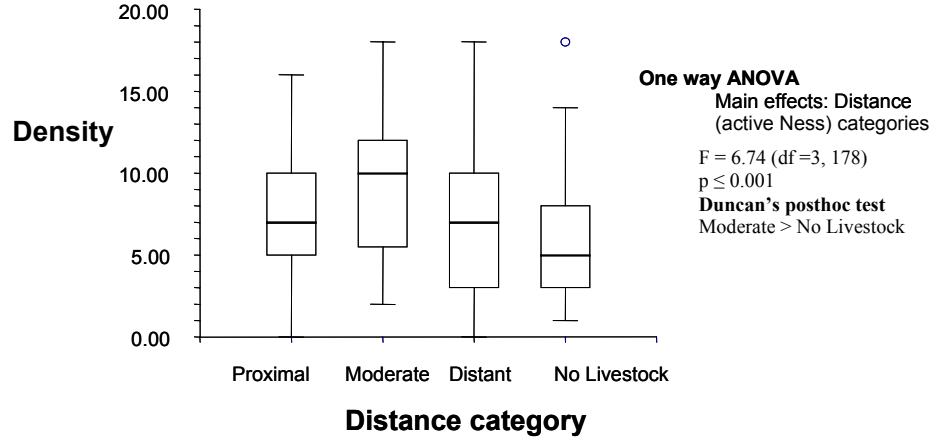
Figure- 6.18: Box & Whisker plot of tree density at different distance categories from existing and evacuated *Maldhari Ness* sites in eastern Gir sanctuary.



b) Browse tree species density

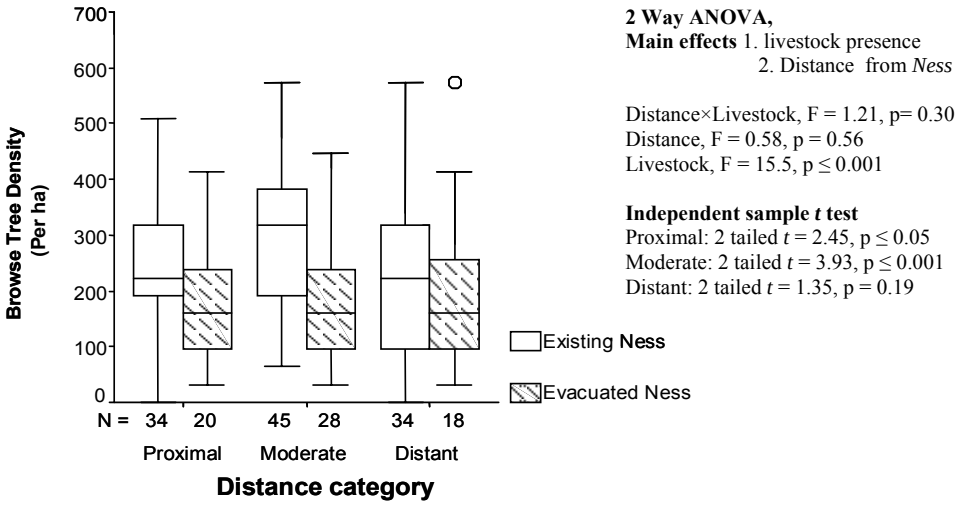
The overall browse species density was different for the varying intensity of livestock grazing i.e. four distance categories from the peripheries of *Maldhari Ness* sites (One way ANOVA, F= 6.74, p ≤ 0.001). However, Duncan's multiple comparison test showed significantly greater browse density in moderately grazed area compared to area devoid of livestock (Duncan's posthoc test, p ≤ 0.05) while other distance (from *Maldhari Ness*) categories i.e. 'proximal' and 'distant' showed no statistical difference from areas devoid of livestock (Figure - 6.19).

Figure- 6.19: Box & Whisker plot of browse tree density at different distance categories from active *Maldhari* sites in eastern Gir sanctuary.



A significant effect of livestock presence (F= 15.5, p ≤ 0.001) was confirmed by 2 way ANOVA. However, the effect of distance from *Ness* (F = 0.58, p = 0.56) or interaction term between livestock presence and distance from *Ness* (F = 1.21, p = 0.30) were not significant. Comparison between grazed and ungrazed area for different distances from centre of the existing and evacuated *Ness* sites, respectively, showed significantly higher browse species density in 'proximal' (Independent sample *t* test, *t* = 2.45, p ≤ 0.05) and 'moderate' (Independent sample *t* test, *t* = 3.93, p ≤ 0.001) categories of grazed areas (Figure - 6.20), while this comparison showed no difference for 'distant' category between grazed and ungrazed areas (Independent sample *t* test, *t* = 1.34, p = 0.19).

Figure- 6.20: Box & Whisker plot of browse species density at different distance categories from existing and evacuated *Maldhari Ness* sites in eastern Gir sanctuary.



c) Tree sapling density: Regeneration

Regeneration of tree species was assessed at different distance categories from *Maldhari* settlements as well as between areas used by livestock and devoid of livestock after controlling for topographic location effect of *Ness* by comparing sapling density of all tree species especially browse species. Non parametric comparison between different distance categories for all tree species sapling density showed no significant difference (Kruskal-Wallis One way ANOVA, χ^2=4.51, p=0.21). However, browse species sapling densities showed significant difference for four distance categories (Kruskal-Wallis One way ANOVA, χ^2=8.24, p ≤ 0.05) (Figure - 6.21). *Posthoc* multiple comparisons of Z values revealed that 'moderate' distance categories had higher sapling density of browse species than 'no livestock' (Kruskal-Wallis Multiple comparison Z-Value test, Z = 2.1808, p ≤ 0.05).

Figure- 6.21: Box & Whisker plot of tree sapling densities at different distance categories from active *Maldhari* sites in eastern Gir sanctuary.

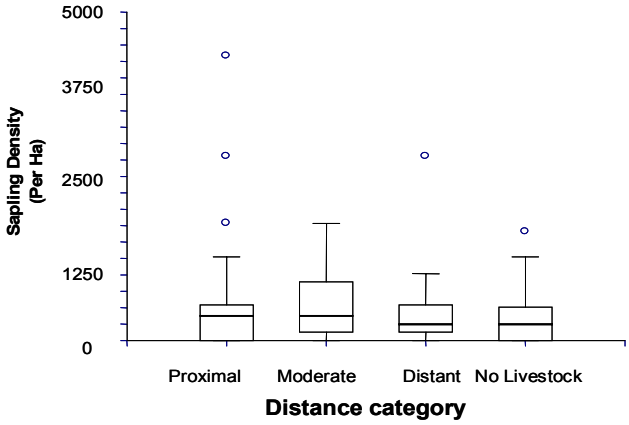
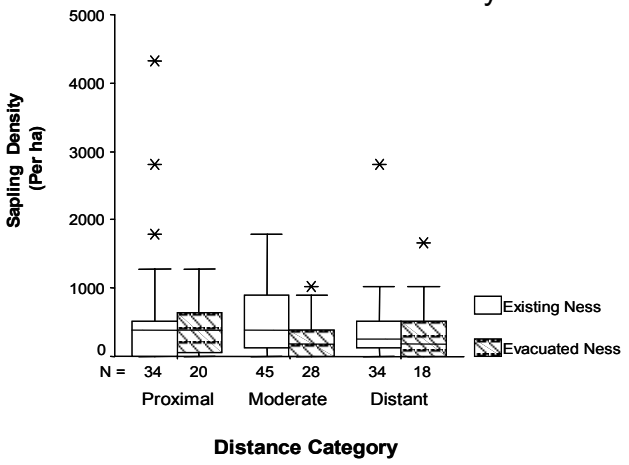


Figure- 6.22: Box & Whisker plot of sapling densities at different distance categories from existing and evacuated *Maldhari Ness* in eastern Gir sanctuary.



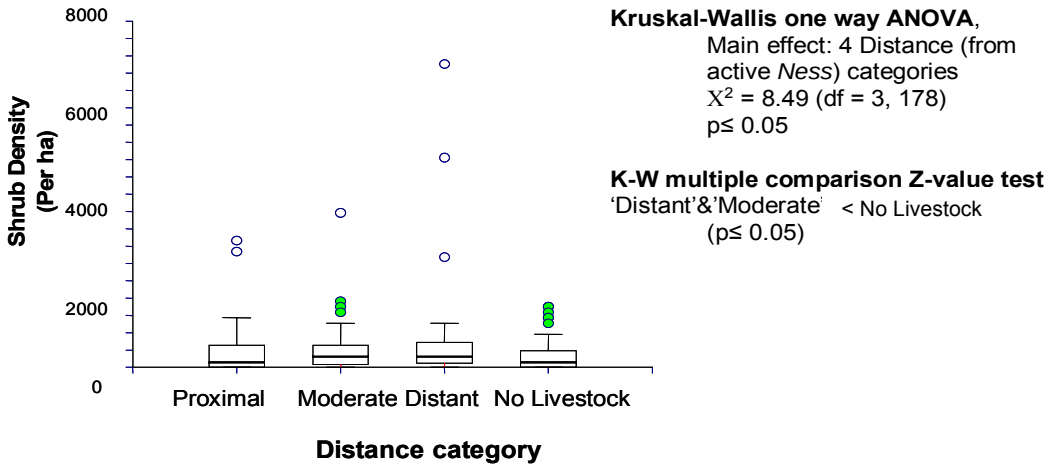
Comparisons of three different distance categories from *Maldhari* settlement for existing and evacuated *Ness* sites were made to assess the effect of livestock grazing on tree regeneration while controlling for the topographic location effect of *Maldhari* settlements. Overall sapling density was not different between existing and evacuated Ness sites for 'proximal' (Mann-Whitney U test, 2 tailed Z = 0.464, p = 0.64) and 'distant' (Mann-Whitney U test, 2 tailed Z = 0.59, p = 0.55) distance categories. However, the sapling density was significantly higher in 'moderate' distance categories (Mann-Whitney U test, 2 tailed Z = 2.38, $p \leq 0.05$) of existing *Ness* (Man-Whitney U = 837.5) than evacuated Ness (Man-Whitney U = 422.5).

Similarly, the sapling densities of browse species were also not different between existing and evacuated *Ness* sites for 'proximal' (Mann-Whitney U test, 2 tailed Z = 0.58, p = 0.56) and 'distant' (Mann-Whitney U test, 2 tailed Z = 0.80, p = 0.42) distance categories while 'moderate' distance category of existing *Ness* (Man-Whitney U = 877.5) was higher than evacuated Ness sites (Man-Whitney U = 382.5) (Mann-Whitney U test, 2 tailed Z = 2.85, $p \leq 0.005$).

6.2.2.3 Assessment of livestock grazing impact on shrub layer

Shrub density was significantly different for the different distance categories from active *Maldhari Ness* sites (Kruskal-Wallis One way ANOVA, $\chi 2 = 8.49$, $p \leq 0.05$). Posthoc multiple comparison of Z-values test showed that 'distant' and 'moderate' distance categories were significantly higher in shrub density than 'no livestock' category (Kruskal-Wallis multiple comparison of Z value test, $p \leq 0.05$) (Figure - 6.23).

Figure- 6.23: Box & Whisker plot of shrub densities at difference distance categories from active *Maldhari* sites in eastern Gir sanctuary.



Comparisons between each of three different distance categories from existing and evacuated *Ness* sites were made to assess the effect of livestock grazing on shrub density while controlling for the topographic location effect of *Maldhari* settlements.

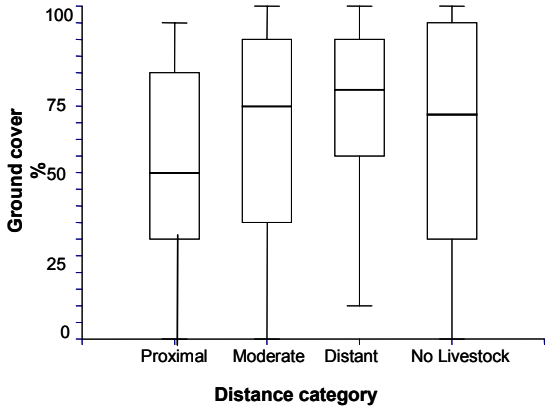
Shrub density was not different between grazed and ungrazed area for 'proximal' (Mann-Whitney U test, 2 tailed Z = 0.11, p = 0.91). However, significant difference was observed for 'moderate' (Mann-Whitney U test, 2 tailed Z = 1.91, p = 0.07) and 'distant' (Mann-Whitney U test, 2 tailed Z = 2.56, $p \leq 0.05$) distance categories, where shrub densities were higher in grazed site (Man-Whitney U test, U = 436 (Distant); U = 347 (Moderate)) was than ungrazed site (Man-Whitney U test, U = 176 (Distant); U = 265 (Moderate)) (Figure - 6.24).

Figure- 6.24: Box & Whisker plot of shrub densities at different distances from existing and evacuated *Maldhari Ness* sites in eastern Gir sanctuary.

6.2.2.4 Assessment of livestock grazing impact on ground cover composition

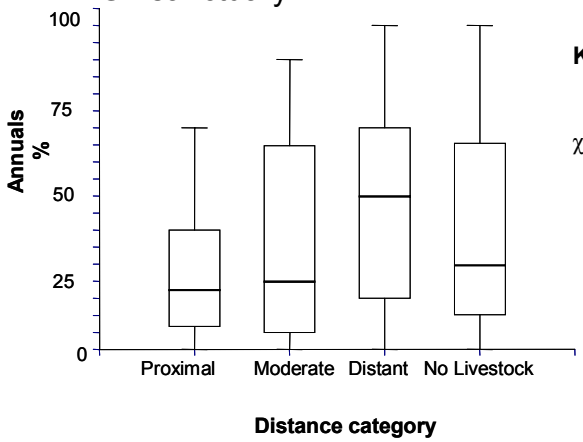
Overall percent ground cover across communities were not different for distance categories (Kruskal-Wallis One way ANOVA, $\chi^2 = 4.45$, p = 0.22) (Figure - 6.25). The percent contribution made by annual grasses (Kruskal-Wallis One way ANOVA, $\chi^2 = 6.99$, p = 0.07) (Figure – 6.26), forbs (Kruskal-Wallis One way ANOVA, $\chi^2 = 5.05$, p = 0.17) and perennial grasses (Kruskal-Wallis One way ANOVA, $\chi^2 = 2.42$, p = 0.49) (Figure - 6.27) were also not different for different distance categories.

Figure- 6.25: Box & Whisker plot of percent ground cover at four different distance categories from Maldhari sites in eastern Gir sanctuary.



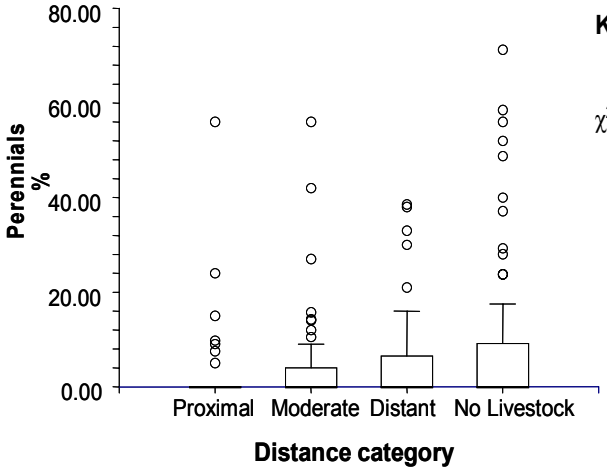
Kruskal- Wallis one way ANOVA,
Main effect: 4 Distance (from active *Ness*) categories
$\chi^2 = 4.45$ p = 0.22

Figure- 6.26: Box & Whisker plot of percent ground cover by annual grasses at four different distance categories from *Maldhari* sites in eastern Gir sanctuary.



Kruskal- Wallis one way ANOVA,
Main effect: 4 Distance (from active *Ness*) categories
$\chi^2 = 6.99$ p = 0.07

Figure- 6.27: Box & Whisker plot of ground cover by perennial grasses at four different distance categories from *Maldhari* sites in eastern Gir sanctuary.



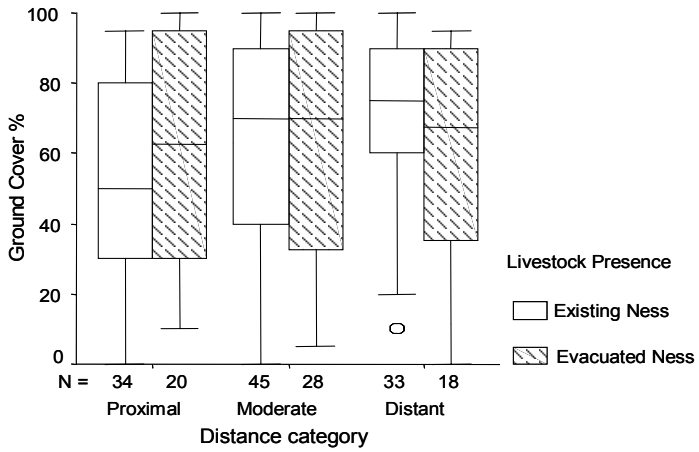
Kruskal- Wallis one way ANOVA,
Main effect: 4 Distance (from active *Ness*) categories
$\chi^2 = 2.42$ p = 0.49

Comparisons of three different distance categories from existing and evacuated *Ness* sites were made to assess the effect of livestock grazing on ground cover and species composition while controlling for the topographic location effects of *Maldhari* settlements. In 'proximal' distance category, percent ground cover (Man-Whitney U test, 2 tailed Z = 1.06, p = 0.29) (Figure - 6.28) as well as contributions of annual grasses (Independent sample *t* test, 2 tailed *t* = 1.72, p = 0.09) (Figure - 6.29) and perennials (Man-Whitney U test, 2 tailed Z= 0.85, p = 0.40) (Figure - 6.30) were different between existing and evacuated *Ness* locations. However, percent contribution of forbs to the overall ground cover was more in existing *Ness* locations than in evacuated *Ness* locations (Independent sample *t* test, 2 tailed *t* = 2.29, $p \leq 0.05$).

In 'moderate' distance category too, percent ground cover (Independent sample *t* test, 2 tailed *t* = 0.43, p = 0.67) as well as percent contribution made by annual grasses (Independent sample *t* test, 2 tailed *t* = 1.09, p = 0.28) and perennial grasses (Man-Whitney U test, 2 tailed Z = 1.34, p = 0.18) were not different between existing and evacuated *Ness* locations while, percent forbs cover (Independent sample *t* test, 2 tailed *t* = 2.14, $p \leq 0.05$) was more in areas used by livestock compared to areas devoid of livestock.

In 'distant' distance category, neither percent ground cover (Independent sample *t* test, 2 tailed *t* = 0.41, p = 0.69) nor contributions of annual grasses (Independent sample *t* test, 2 tailed *t* = 0.43, p = 0.67), perennial grasses (Man-Whitney U test, Z = 0.62, p = 0.53) and forbs were (Man-Whitney U test, Z = 0.65, p = 0.51) different between existing and evacuated *Ness* locations.

Figure- 6.28: Box & Whisker plot of percent ground cover at different distances from existing and evacuated *Maldhari Ness* sites in eastern Gir sanctuary.



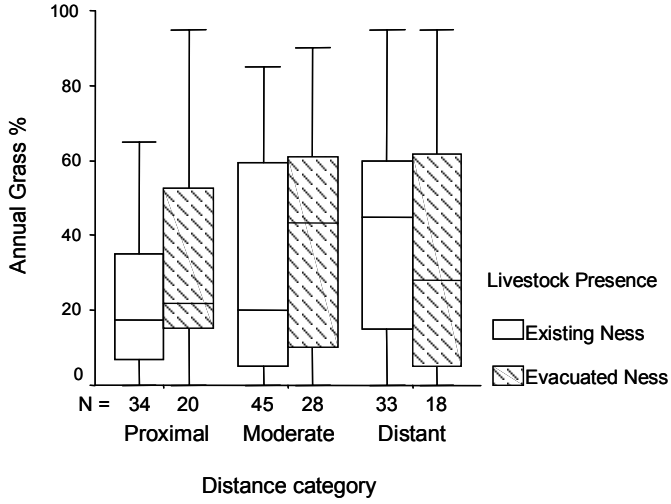
Man-Whitney U test

Proximal: 2 tailed Z = 0.94, p = 0.35

Independent sample *t* test,

Moderate: 2 tailed *t* = 0.43, p = 0.67
Distant: 2 tailed *t* = 0.41, p = 0.69

Figure- 6.29: Box & Whisker plot of percent ground cover by annual grasses at different distances from existing and evacuated *Maldhari Ness* sites in eastern Gir sanctuary.



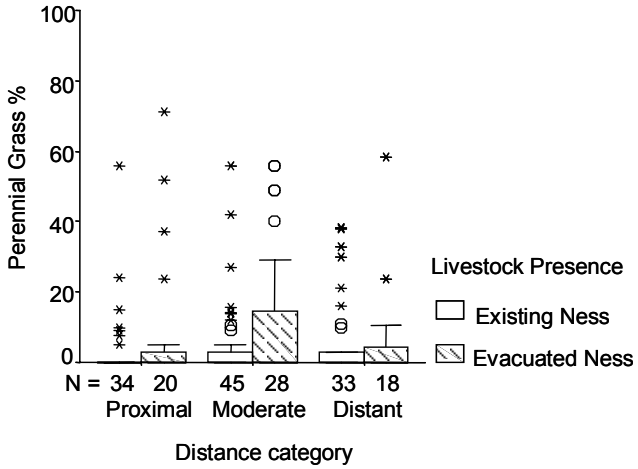
Independent sample *t* test,

Proximal: 2 tailed *t* = 1.72, p = 0.09

Moderate: 2 tailed *t* = 1.09, p = 0.28

Distant: 2 tailed *t* = 0.43, p = 0.67

Figure- 6.30: Box & Whisker plot of percent ground cover by perennials grasses at different distances from existing and evacuated *Maldhari Ness* sites in eastern Gir sanctuary.



Man-Whitney U test,

Proximal: 2 tailed Z = 0.85, p = 0.40

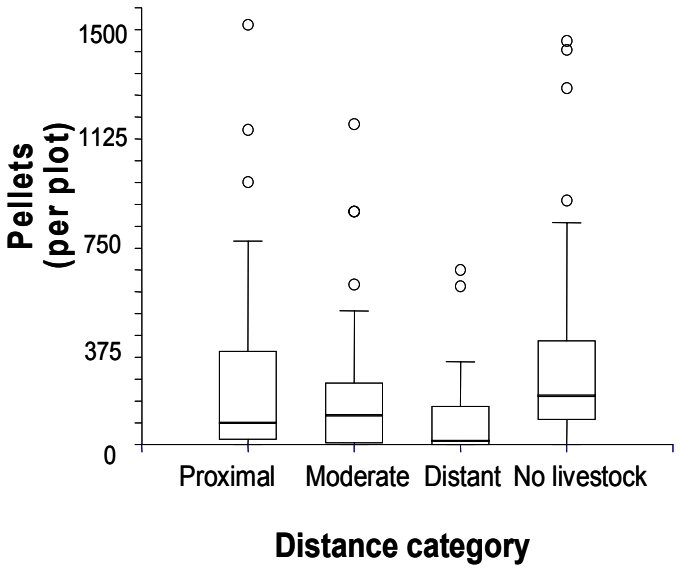
Moderate: 2 tailed Z =1.34, p = 0.18

Distant: 2tailed Z = 0.62, p = 0.53

6.2.2.5 Chital and other wild ungulate pellet abundance in different distance categories from active and evacuated *Ness* sites.

Chital pellet density was different in different distance categories i.e. grazing intensity (Kruskal-Wallis One way ANOVA, χ^2 = 24.48, p ≤ 0.001). Chital pellet density was higher in proximal category and it decreases as distance from *Maldhari* settlement increases i.e. up to the periphery of grazing area of active *Ness* site (Figure- 6.31). Pellet density was higher in 'moderate' and 'proximal' distance categories than 'distant' distance category (Kruskal-Wallis multiple comparison Z-value test, p≤ 0.05). The pellet density of wild ungulates other than chital was also different for different grazing distance categories (Kruskal-Wallis One way ANOVA, χ^2 = 11.65, p ≤ 0.01). However, the difference in pellet density was observed only between 'moderate' and 'no livestock' categories (Kruskal-Wallis multiple comparison Z-value test, p≤ 0.05) (Figure - 6.32).

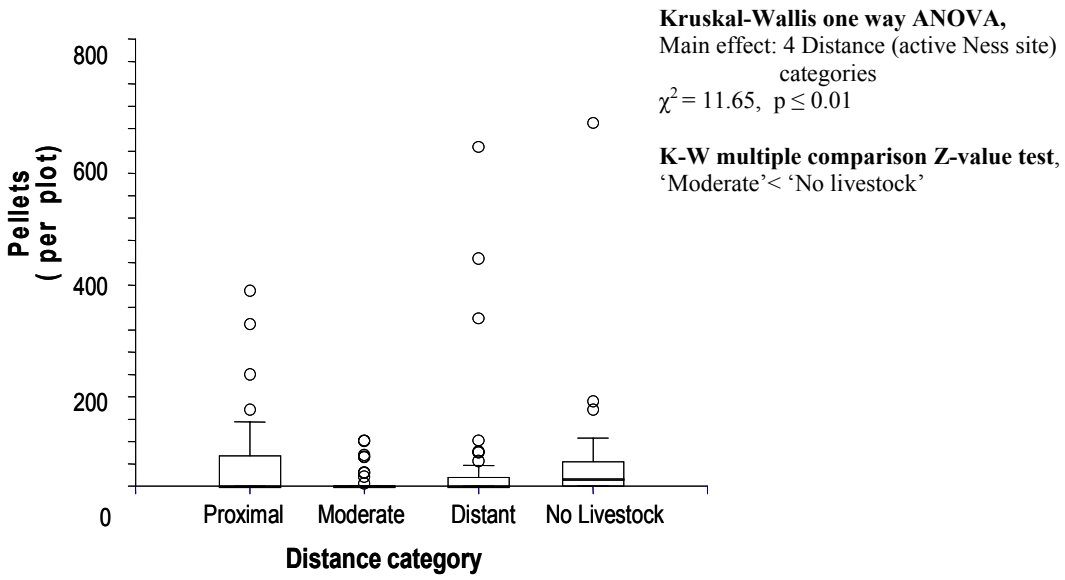
Figure- 6.31: Box & Whisker plots of chital pellet densities at four distance categories from active *Maldhari Ness* in eastern Gir sanctuary.



Kruskal-Wallis one way ANOVA,
Main effect: 4 Distance (active Ness site) categories
χ^2 = 24.48, p ≤ 0.001

K-W multiple comparison Z-value test,
'Proximal' & 'Moderate' > 'Distant' (p≤ 0.05)

Figure- 6.32: Box & Whisker plots of other wild ungulates pellet densities at four distance categories from active *Maldhari* settlements in eastern Gir sanctuary.



Comparisons of three different distance categories from *Maldhari* settlement for existing and evacuated *Ness* sites were made to assess the effect of livestock grazing on pellet densities of chital and other wild ungulates while controlling for the topographic location effect of *Maldhari* settlements. Pellet densities of chital (Man-Whitney U test, $Z = 1.5$, $p = 0.13$) (Figure - 6.33) and other ungulates (Man-Whitney U test, $Z = 1.24$, $p = 0.21$) (Figure - 6.34) were not different between existing and evacuated *Ness* sites for 'proximal' distance category. In 'moderate' distance category, pellet density of chital was marginally different between existing and evacuated *Ness* sites (Man-Whitney U test, $Z = 1.76$, $p = 0.09$). However, in 'moderate' distance category, pellet density of other ungulates was significantly higher for evacuated *Ness* sites (Man-Whitney U test, $Z = 3.45$, $p \leq 0.001$). In 'distant' distance category, chital pellet density was significantly higher in existing *Ness* sites than evacuated *Ness* sites (Man-Whitney U test, $Z = 3.80$, $p \leq 0.001$) but pellet density of other ungulate were not different between existing and evacuated *Ness* sites (Man-Whitney U test, $Z = 0.62$, $p = 0.54$).

Figure- 6.33: Box & Whisker plot of chital pellet densities at different distances from existing and evacuated *Maldhari Ness* sites in eastern Gir sanctuary.

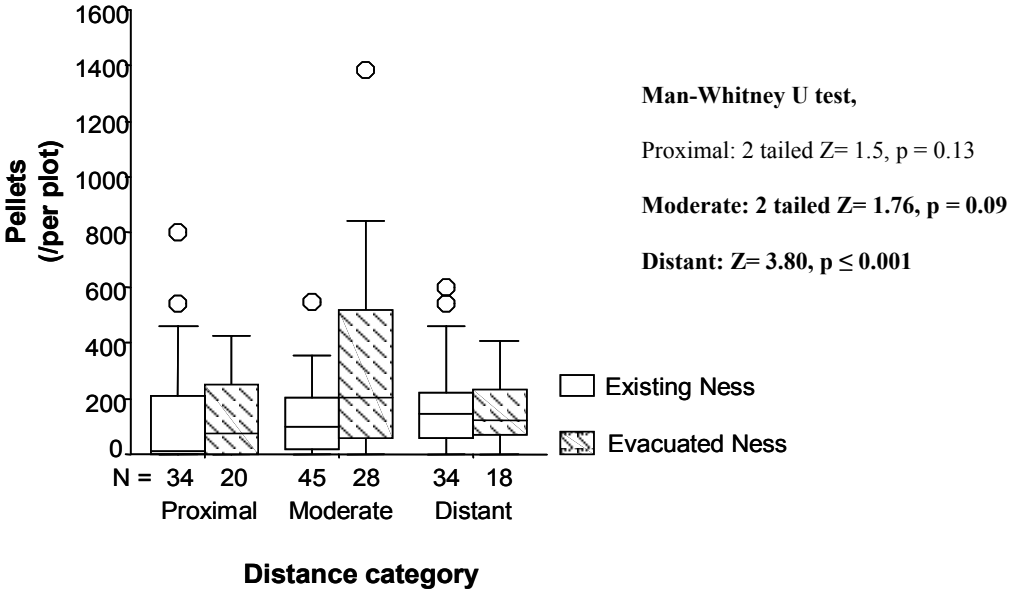
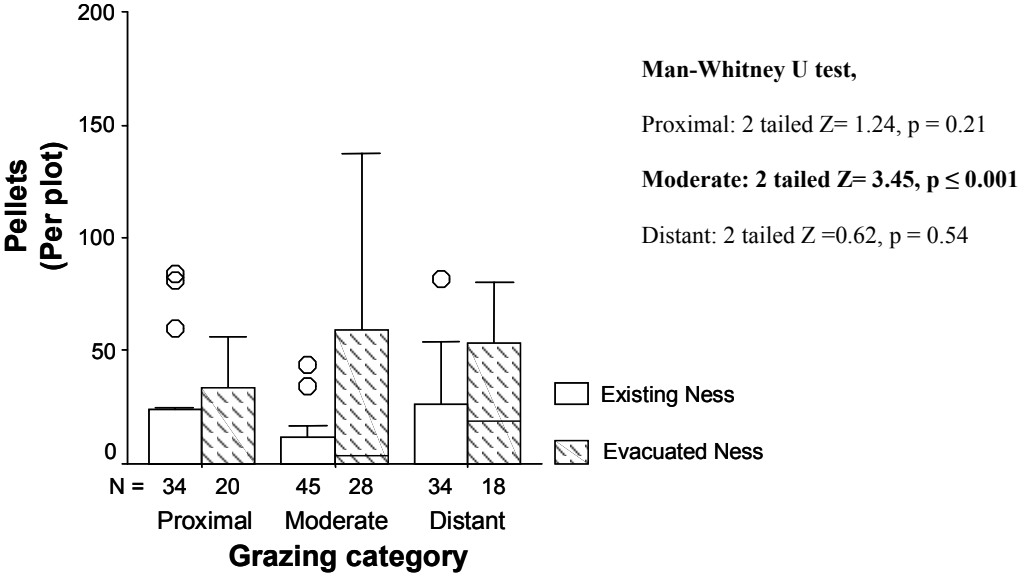


Figure- 6.34: Box & Whisker plot of pellet densities of other wild ungulates at different distances from existing and evacuated *Maldhari Ness* sites in eastern Gir sanctuary. Bars in box plots are standard errors.



6.4 Discussion

6.4.1 Indirect impact of livestock grazing on forage availability

6.4.1.1 Above ground biomass and species composition

Interactions among large mammalian herbivores are mediated largely through their grazing and browsing impacts on vegetation (Vesey-Fitzgerald, 1960; Bell, 1970; Eltringham, 1974; Murray & Illius, 2000). Above ground biomass within and outside exclosures increased with a decrease in grazing intensity (Figure - 6.3). However, the above ground biomass of herbaceous species which contributed to chital diet (mainly annual grasses and forbs, Chapter -7) showed no decreasing trend with respect to distance from *Ness* sites i.e. the livestock grazing intensity (Figure - 6.4). The short term exclusion of large herbivores (for one growing season) showed drastic increment in the biomass of chital food items in the area used by livestock. However, chital food items did not increase significantly after short term grazing exclusion in areas devoid of livestock. It seems likely that grazing activity of large coarse feeders like cattle and buffalo kept biomass of perennial grasses low which gives an upper edge to the annual grasses and forbs (Vesey- Fitzgerald 1960, Bell 1970, 1971, McNaughton 1976), which substantially contribute to the chital diet (Chapter -5). With reduced competition from perennial grasses these annual grasses and forbs would flourish in areas sympatric with livestock (see Figure - 6.6 & 6.7).

Herbaceous composition is not determined by physical environment independent of herbivores. Instead, herbivores exert strong influence on herbaceous composition and grass growth forms (McNaughton, 1983). Species diversity (Shannon-Wiener Index) was higher in the area less intensively grazed by livestock; and ecotypes of perennial and annual grasses that predominantly occur in the area intensively used by coarse grazers i.e. cattle and buffalo were dwarf, low growing forms with short internodes. These grasses invest heavily in rapidly growing leaf tissues. Grasses that occurred in ungrazed areas, in contrast, were more erect, taller-growing species that invest heavily in stem and other supporting tissues (McNaughton *et al*. 1989). However, it was found that the species diversity of grasses and forbs found in chital diet was higher in the areas used by livestock compared to areas devoid

of livestock irrespective of exclosure treatment. In previous studies it is found that grazing reduces competition between herbaceous species and promotes species richness and diversity within a community (Karki *et al*, 2000, Green & Kauffman 1995, Noy-Meir 1995; Detling, 1998). However, the short term grazing exclusion (one growing season) showed no change in the herbaceous species diversity. The result is supported by Beebe *et al* (2002), they too found very little change in species diversity over a short duration grazing exclusion. One year grazing exclusion did not permit species diversity to change drastically, however species diversity was maximum in moderately grazed area. Thus, result supports intermediate disturbance hypothesis proposed by Grime (1973).

Overall above ground herbaceous production was comparable with the other such experiments in tropical regions (Singh & Misra, 1969; Berwick, 1974). Apparently, above ground biomass drastically declines in areas proximal to *Maldhari* settlements. Substantial removal of herbaceous biomass by livestock might be altering the natural floral composition and subsequently affecting the ecosystem processes. However, previous studies (Owen-Smith 1988; Milchunas & Lauenroth 1993) suggest that such effects might not necessarily be detrimental to the ecosystem.

Short term exclusion of large herbivores did not show complete reversal of the long term effect of intensive herbivory. However, the observed increase in above ground biomass production indicated the high potential for recovery (Berwick, 1974). The maximum removal of above ground production by large herbivores was 43 % of total production in areas used by livestock; and if assumed similar consumption by wild herbivores in both the sites i.e. with and without livestock, the removal of above ground production by domestic livestock was just 21.9 %. Berwick (1974) cites communication of K. T. B. Hodd where he felt that the effects of overgrazing by livestock extended up to 1.6 km. However, the area with sympatric livestock grazing produced 68 % of full production in area devoid of livestock which indicates ‘good’ range condition (Humphrey, 1949).

6.4.1.2 Short term and long term impact of livestock grazing on browse production

Browse forms an important component of the diets of ungulates living in the arid regions (Nott & Savage, 1985; Milton, 1988). Berwick (1974) reported higher browse productivity in eastern Gir sanctuary compared to National Park and western part of the sanctuary. It is empirically observed that plants react to herbivory in two general ways; first, they may provide protection from grazing by producing toxins or reducing nutritional values by increasing lignin, ash and silica content or morphological features such as toughness or spines and, secondly, they may compensate for the biomass actually removed (Jameson 1963; McNaughton 1979).

The estimated browse production within the reach of wild herbivores on lopped *Anogeissus latifolia* trees was higher than the paired unlopped trees of same species which explained the short term compensatory response of this species to lopping. Similarly, the browse production on randomly selected *Anogeissus latifolia* trees in areas used by livestock had more browse within the reach of wild herbivores than on similar sized *Anogeissus latifolia* trees in areas devoid of livestock which explained the long term compensatory response to lopping. The results are supported by the findings of Belsky (1986) who reported many instances where the foraged plants respond to defoliation by replacing lost reproductive or somatic tissues, i.e. showing partial or total compensation.

The information on the plant tolerance to browsing and lopping in subtropical region was not available. However, Teague (1985) reported two- to three fold enhanced leaf production in *Acacia karoo* trees browsed by goats in tropical savannah ecosystem. Crawley (1983) discussed compensatory mechanisms of plant regrowth. However, whatever, the mechanisms of compensation, the browse harvest by lopping should not cross the optimal level of herbivore harvest, which maximizes the overall net plant productivity (McNaughton, 1983; Belsky, 1986). Berwick (1974) reported level of proportionate browse use with respect to browse production in Gir well below than recommended by several studies in temperate regions (Garrison, 1953; Hubbard & Sanderson, 1960; Baker, 1941). Sharma (1995) also reported an average of 30 % consumption of the available browse by large herbivores in

Gir protected area. In case of Gir, the results of this study as well as previous ones suggest that browse harvest (browsing and lopping at current level) does not hamper the plant productivity or the browse availability within reach of wild ungulates but enhances available browse in case of *Anogeissus latifolia*. However, increased intensity and frequency of lopping may be detrimental to tree survival by low seed production or even mortality

6.4.2. Indirect impact of livestock grazing on vegetation association structure and composition

6.4.2.1 Structure and composition of vegetation associations

Plant communities or vegetation associations within intensive site of eastern Gir sanctuary studied during this study were similar to results of previous research (Berwick, 1974; Sharma, 1995) and therefore intensive study site reflects the broad vegetation characteristic of entire Gir forests. Eastern Gir sanctuary supported higher diversity of plants coupled with greater plant and animal diversity (Berwick, 1974). Vegetation in eastern Gir sanctuary was more heterogeneous compared to rest of the protected area. The role of patchy and intensive livestock grazing on structural heterogeneity in vegetation community might be subtle but cannot be overruled (Tayler & Walker, 1978; Vessey-Fitzgerland, 1973). Tree density of similar vegetation associations between this study and Sharma (1995) are comparable. However, tree density estimates of this study are not comparable with Berwick (1974) and Khan (1993) because former reported density of browse species only while latter reported tree and shrub density based on height, rather than life-form of species.

Shrub density showed a positive correlation with tree density (Pearson's correlation, $r = 0.916$, $p \leq 0.01$). Such positive interaction between tree and shrub vegetation has been found by Weltzin & Coughenour (1990). As expected highest densities of tree, shrub as well as sapling were observed in the moist riverine vegetation i.e. *Anogeissus latifolia – Acacia catechu – Terminalia crenulata* owing to favourable microclimatic and soil condition (Sharma, 1995). The browse density was more than 80 % in all vegetation associations except *Tectona grandis - Acacia catechu* association which had

42.4 % browse trees of total tree density. Highest browse density (345.5 browse trees/ha) was observed in dense riverine habitat i.e. *Anogeissus latifolia – Acacia catechu – Terminalia crenulata* however, percent browse density was more (97 %) in thorn mixed forest i.e. *Ziziphus mauritiana – Anogeissus latifolia – Lanea coromondelica.* Sapling density of browse and non-browse tree species was relatively higher in all vegetation associations which suggest no detrimental effect of livestock grazing on shrub layer as evident from a study in African savannas (Tayler & Walker, 1978). Besides, low abundance of browsers (Chapter-5) in the intensive study area justifies the higher browse species density. Ground cover was more than 50 % in all plant communities. Maximum ground cover especially with grass species was in *Phyllanthus emblica – Terminalia crenulata – Acacia leucophloea* community. Ground cover composition was predominantly contributed by annuals like *Apluda mutica, Panicum sp.* and *Aristida sp.* in almost all plant communities. Perennial grasses like *Eremopogon foveolatus* and *Heteropogon contourtus* were patchily distributed and never contributed more than 5 % to total ground cover in any plant community. Since the substantial part of sampled area is used by livestock, significant contribution of unpalatable herbaceous species to the total cover was expected (Fleischner, 1994; Hobbs & Huenneke 1992). However, the contribution of unpalatable herbaceous species to total ground cover never exceeded 5 % in any of these vegetation associations.

6.4.2.2. Assessment of vegetation parameters along the grazing gradient

Grazing intensity and vegetation degradation around artificial features of the landscape such as waterholes and human settlements have been well documented in the semi-arid rangelands of North America (Fusco *et al.* 1995), Africa (Tolsma *et al*. 1987; Perkins &Thomas 1993; Van Rooyen *et al.* 1994; Moleele & Perkins 1998; Turner 1998) and Australia (Andrew & Lange 1986; Pickup & Chewings 1994; James *et al*. 1999). These grazing orbits provide useful systems in which to study the responses of vegetation and other variables to a range of grazing intensities (Andrew, 1988; Riginos & Hoffman, 2003).

The effect of varying intensity of livestock grazing on tree density could not be detected, perhaps due to patchy and spatially heterogeneous

vegetation in eastern Gir sanctuary (Berwick, 1974; Sharma, 1995). But density of palatable species exhibited a trend where maximum browse species density was in all three distance categories of areas of current livestock use compared to evacuated sites (Figure - 6.20). Abundant browse species like *Acacia sp.* and *Ziziphus sp.* have protective morphological features to reduce ungulate depredation, nonetheless they provide highly nutritious (Chapter-7) browse in substantial quantity (Berwick, 1974; Sharma, 1995).

Sapling density was expected to be lower in the moist mixed riverine habitat as 1) most of the *Maldhari* settlements occupy this habitat 2) livestock select riverine habitats for shade (cooler temperatures), and water and therefore spend disproportionately more time in this habitat (Roath & Krueger 1982; Gillen *et al*. 1984; & this study). However, sapling density was maximum (612 ± 115 stems/ha) in this habitat i.e. *Anogeissus latifolia – Acacia catechu – Terminalia crenulata*. Besides, no discernible effect of grazing intensity i.e. four distance categories from active *Ness* locations, on sapling density in this plant community was observed (Kruskal-Wallis One way ANOVA, $\chi^2 = 1.86$, p=0.60).

Lower shrub densities closer to *Ness* sites compared to moderate distance could be attributed to trampling by heavy hoofed cattle and buffalo. However, trends in shrub densities (Figure - 6.24) showed higher shrub densities in the grazing areas of active *Ness* sites than evacuated *Ness* sites. Results are supported by Bock & Bock (1998), who have explained the role of livestock grazing in facilitating the growth of woody species at the expense of herbaceous species.

Effect of livestock grazing on ground layer was expected to be more discernible than tree and shrub layers (Hayes & Holl, 2003). The impact of livestock grazing magnifies on ground cover and species composition through trampling (Cumming & Cumming, 2003) and biomass removal (see review by Fleischner, 1994). However, no significant trend in percent ground cover could be captured due to higher ground cover variability between and within vegetation types. Nevertheless, results indicate an improvement in ground cover with decreasing grazing intensity (Figure - 6.25). Compared to annuals, perennials were less resilient to livestock grazing as percent contribution of

perennials was lower than annual in all grazing intensity categories. Interestingly, low to moderate intensity of livestock grazing seemed improving percent cover of palatable annuals at the cost of coarse perennials. Though contribution of perennial grass cover showed slight increase after evacuation of livestock populations, recovery in perennials seems slower comparatively, nonetheless. Along with percent herbaceous ground cover, species richness of herbaceous species too showed a better trend in low to moderate intensity of livestock grazing.

Overall, result suggests that ground cover and species richness of palatable ground flora attained better condition in low to moderate livestock grazing intensity rather than complete exclusion of livestock. The results are supported by studies on annual grasses (Grubb, 1986; Collins, 1987; McNaughton, 1993), dicots (Knapp *et al*. 1999; Bullock *et al*. 2001) and annual dicots (Talbot *et al*. 1939; Fensham, *et al*. 1999; Hayes & Holl, 2003). It is also likely that in ungrazed sites, competition with perennials negatively affects annuals (Collins, 1987; Howe, 1999), while in intensively grazed sites trampling negatively affects overall ground cover (Cumming & Cumming, 2003).

6.4.3 Response of chital and other wild ungulates to livestock grazing

Major ungulate species i.e. chital, sambar and nilgai are generalist species in terms of use and preference of different vegetation associations (Khan, 1993; Sharma, 1995). Pellet densities of chital and other wild ungulates were compared between different grazing categories (livestock grazing intensity) irrespective of vegetation associations. Even though these ungulates seem to have broad habitat preferences (Berwick, 1974; Khan, 1993; Sharma, 1995), they may respond more to microclimatic or microhabitat conditions than broad vegetation types (Bowyer *et al*. 1999). Livestock grazing creates structural heterogeneity within habitats (Tayler & Walker, 1978; Vessey-Fitzgerland, 1973) and in turn, might affect microhabitat features. Pellet group method is widely used method for assessing habitat use by free ranging ungulates (Leckenby, 1968; Cairns & Telfer, 1980; Colllins & Urness, 1984; Leopold *et al*. 1984; Loft, 1988; Borkowski & Ukalska, 2007) and it provides unbiased and reliable estimates of habitat use by ungulates (Loft, 1988).

The attempt was made to assess the response of chital and other wild ungulates, especially any deterrence to such altered microhabitat conditions in different categories of livestock grazing intensity i.e. distance from active and evacuated *Ness* sites.

However, neither chital nor other wild ungulate showed significant negative trend with respect to livestock grazing. Surprisingly, chital and other wild ungulates exhibited similar trends as their pellet abundances were higher within proximal category i.e. between 200m to 600m from active *Ness* site. Nevertheless, comparison between active and evacuated *Ness* sites for three distance categories (from periphery of the *Ness* location) showed slight improvement in pellet abundance after evacuation of livestock (Figure - 6.33 & 8.34). Higher wild ungulate pellet abundance in proximal distance categories of active as well as evacuated *Ness* sites could have been resulted owing to topographic characteristic of *Ness* locations i.e. presence of perennial water and cover (Figure - 6.31 & 6.32).

In a previous study (Bock & Bock, 1998) it was found that livestock grazing facilitates the growth of woody vegetation by removal of herbaceous biomass which in turn creates mosaic of open and bushy habitat patches due to their heterogeneous habitat use for grazing. Such bushy patches provide security cover, which is important for wild ungulates to escape from lions and leopards. Such observations lend support to occasional higher pellet counts in grazed sites (see figure - 6.31 & 6.32 for outliers) and therefore could be viewed as peculiarity of grazed site rather than sampling artefact or chance occurrence.

Overall, the results of this study revealed no negative effect of livestock grazing on chital habitat use as indicated by pellet abundance. In case of other wild ungulates, effect of livestock grazing activity on pellet abundance could be detected only for moderate distance category (600 to 1400 m) where pellet abundance was higher in evacuated sites than active sites. However, wild ungulate distribution does not seem affected within proximal distance category due to temporal segregation in habitat use for different activities by wild and domestic ungulates. Whereas in distant distance category, habitat use by other wild ungulates was unaffected probably due to low and infrequent intensity of livestock activity in that area.

CHAPTER 7

Synthesis & Conclusion

Ungulate populations play a keystone role in forest ecosystem (Crawley, 1983; Owen-Smith, 1987; Karanth & Stith, 1999). Livestock grazing is widespread in most forests of India and they potentially compete for important resources (Kothari *et al*. 1989). Little site specific data exist on the ecology of wild ungulates or the impact of livestock on forest communities. Currently a raging debate between preservationist and human right activists is ongoing on the resettlement of forest dwellers (tribal communities) within the forest lands of India (Narien *et al*. 2005, Sekhsaria 2007). Such debates are fuelled by activism rather than ecology (Mishra *et al.* 2004) but see Madhusudan (2004).

Most of the natural ranges of chital are shared with livestock. Hence, in this context, the ecological interface between chital and livestock (cattle and buffalos) is required to be addressed for better understanding of chital ecology and eventually help in designing conservation and management strategies pertaining to livestock regulation and habitat manipulation. My study design and hypothesis addressed chital-livestock interface at two spatial and three temporal scales. Direct impact of sympatric livestock (short to medium term response) grazing was thought to be reflected in population performance of chital; and therefore population demography; activity and ranging patterns; habitat use and selection patterns; as well food habits of chital were studied. Indirect impacts of livestock grazing (medium to long term response) 1) impact on forage availability 2) alteration in plant community structure and composition were also studied.

Chital population was all time high in Gir forests. Among all ungulate species chital is common and widely distributed throughout Gir PA, and contributes 92.7 % of the total wild ungulate density. Chital population has increased almost fourteen times from 1970 to 2006. Realized rate of increase for wild ungulates as a whole was 0.070 and for chital population it was 0.071; which is comparable with other tropical and savanna ungulates elsewhere. My research has shown that density estimates obtained by road counts can be biased. These biases can result in being doubled and are prominent where habitat manipulation is common along roads. Herein, I recommend the sampling of systematically distributed foot transects for obtaining unbiased and reasonably precise density estimates.

Ungulate densities in Gir were determined primarily by the productivity of the habitats as they were correlated with rainfall. Total wild ungulate and chital densities increased by a factor of 0.6 from east sanctuary (38.8 & 35.1 km^{-2}) to west sanctuary (60.1 & 55.3 km^{-2}). Due to confounding role of rainfall related habitat productivity and local adaphic factors, negative influence of sympatric livestock grazing on demographic characteristics of chital like density, group sizes and body conditions could not be detected at landscape level scale. At site specific scale, after controlling for confounding effects of rainfall related habitat productivity, comparison of densities, group sizes and body condition of chital between two ecologically similar sites differing only in term of livestock presence within this landscape, revealed that chital density was higher in areas devoid of livestock during resource crunch period; nonetheless group sizes and body condition were not different between areas used by livestock and devoid of livestock.

Chital preferentially used *Acacia-Ziziphus* scrubland while livestock preferred *Boswelia-Lanea-Terminalia* habitat. Dietary overlap between chital and cattle-buffalo was comparatively low during all seasons. Maximum dietary overlap was observed during the resource crunch period i.e. summer and minimum during resource abundant period i.e. winter. Cattle and buffalo with relatively larger body size relied on bulk forage i.e. abundant and perennial grasses, while the diet of chital was dominated by low fiber, highly digestible and nutritious browse and forbs. The foraging strategy of cattle and buffalo was observed to be time minimizing, whereas the chital foraging strategy was to be energy maximizing. Even the pellet count study revealed no negative impact of livestock grazing on chital habitat use pattern. It can be inferred that livestock look for ‘quantity’ and chital look for ‘quality’ during their food search. Hence, at current ecological condition livestock and chital both keyed in on similar habitats to obtain their food.

Palatable ground cover composition, cover and biomass attained better condition in moderate intensity of livestock grazing (within the foraging area of livestock but more than 500 m away from *Maldhari* settlement). The density of browse species exhibited a trend where maximum density was in areas with sympatric livestock than in areas devoid of livestock. Browse production

available to wild ungulates on *Anogeissus latifolia* was higher in areas used by sympatric livestock compared to areas devoid of livestock. Even lopped *Anogeissus latifolia* had more available browse production than unlopped trees. However, it is important to mention that an increase in the intensity and frequency of lopping may be detrimental for tree survival. Perennial grass species and shrubs were impacted close to *Ness* sites due to grazing and trampling by livestock. However, trends in shrub densities showed higher densities in moderately grazed areas compared to ungrazed areas. No discernible impact of livestock grazing on tree or sapling densities was observed within the intensive study area of eastern Gir sanctuary. Moderate grazing intensity arrests the vegetation succession in intermediate seral stage by postponing the climax stage in plant communities (McNaughton, 1979; Fleischner, 1994), which create ideal habitat and forage conditions for wild ungulate community especially for chital. To avoid the intensive grazing and trampling near Ness sites livestock numbers should be regulated at settlement level. Larger *Maldhari* settlements should be segregated into smaller ones so as to maintain the low to moderate intensity of livestock grazing. Besides, to facilitate the natural system to recuperate from the negative impact related to human settlement, Maldhari locations should be rotated every three to five years so as to minimize the detrimental effects in terms of regeneration of perennial grasses.

References

Ables, D.E. (1974) Introduction: Pages 1-7 in Ernest D. Ables (ed) *The Axis deer in Texas*. The Caesar Kleberg Research Program in Wildlife Ecology.

Ables, D.E., editor (1974) *The Axis deer in Texas*. The Caesar Kleberg Research Program in Wildlife Ecology. 83 pp.

Abrams, P. A. (1980) Some comments on measuring niche overlap. *Ecology,* 61:44 - 49.

Abrams, P. A. (1998) High competition with low similarity and low competition with high similarity: exploitative and apparent competition in consumer–resource systems. *The American Naturalist*, 152:114–128.

Allcock, K. G. & Hik, D. S. (2003) What determines disturbance-productivity-diversity relationships? The effect of scale, species and environment on richness patterns in an Australian woodland. *Oikos* 102, 173–185.

Altmann, J. (1974) Observational Study of behaviour: Sampling methods. *Behaviour*, 49: 227-267.

Anderson, J. (1953) Statistical analysis of compositional data. *Journal of Royal Statistical Society*, 44: 139-177.

Anderson, V. J. & Briske, D. D. (1995) Herbivore induced species replacement in grasslands: is it driven by herbivory tolerance or avoidance. *Ecological Applications*, 5(4): 1014-1024.

Andersons, D. R. Laake, B., Crain, B. & Burnham, K. (1979) Guidelines for transect sampling of biological population. *Journal of Wildlife Management,* 43 (1): 71-79.

Andrew, M.H. & Lange, R.T. (1986) Development of a new piosphere in arid chenopod shrubland grazed by sheep. II. Changes to the vegetation. *Australian Journal of Ecology*, 11: 411–424.

Andrew, M.H. (1988) Grazing impact in relation to livestock watering points. *Trends in Ecology and Evolution*, 3: 336–339.

AOAC, (1987) *Official methods of analysis* (13th edition)—Association of Official Analytical Chemists, Washington, US.

Archer, S. (1989) Have southern Texas savannas been converted to woodland in recent history? *The American Naturalist,* 134: 545-561.

Arnold, G. W. (1985) Regulation of forage intake. Pages 81 - 101 in (Ed) R. J. Hudson and R.G. White. *Bioenergetics of wild herbivores*. CRC Press Boca Raton, Florida.

Arsenault, R. & Owen-Smith, N. (2002) Facilitation versus competition in grazing herbivore assemblages. *Oikos,* 97:313-318.

Augustine, D. J. & McNaughton, S. J. (1998) Ungulate effects on the functional species composition of plant communities: Herbivore selectivity and plant tolerance. *Journal of Wildlife Management*, 62(4): 1165 -1183.

Bagchi, S. (2001) *Resource selection and resource partitioning among wild ungulates in the tropical semi arid forests of Ranthambhore National Park, Rajasthan*. MSc Thesis. Saurashtra University, Rajkot.

Bagchi, S. Goyal, S. P. & K. Shankar (2003) Habitat separation among ungulates in dry tropical forests of Ranthambhore National Park, Rajasthan. *Tropical Ecology*, 44 (2): 175- 181.

Bailey, D. W., Gross, J., Laca, E., Rittenhouse, L., Coughenour, M., Swift, D. & Sims, P. (1996) Mechanisms that result in large herbivore grazing distribution patterns. *Journal of Range Management*, 49: 386-400.

Bailey, R. E. & Putman, R. J. (1981) Estimation of fallow deer (*Dama dama*) populations from faecal accumulation. *Journal of Applied Ecology*, 18: 697-702.

Baker, W.L. (1941) Effects of gypsy moth defoliation on certain forest trees, *Journal of Forestry*, 39: 1017 -1022

Ball, J. P., Danell, K. & Sunesson, P. (2000) Response of an herbivore community to increased food quality and quantity: an experiment with nitrogen fertilizer in a boreal forest. *Journal of Applied Ecology* 37: 247–255.

Barrette, C. (1991) The size of Axis deer fluid groups in Wilpattu National Park, Sri Lanka. *Mammalia*, 55: 207-220.

Barrett, M. A. & Stiling, P. (2006) Effects of Key deer herbivory on forest communities in the lower Florida Keys. *Biological Conservation*, 129: 100-108.

Bartumeus, F., da Luz, M. G. E., Viswanathan, G. M. & Catalan, J. (2005). Animal search strategies: a quantitative random-walk analysis. *Ecology*, 86: 3078 - 3087.

Bayliss. P. (1985) The population dynamics of red and western grey kangaroos in arid New South Wales, Australia. 1. Population trends and rainfall. *Journal of Animal Ecology*, 54: 125 -129.

Beebe, J., Everette, R., Scherer, G. & Davis, C. (2002) *Effect of fertilizer applications and grazing exclusion on species composition and biomass in wet meadow restoration in eastern Washington*. Research Paper PNW-RP-542, Pecific Northwest Research Station, Forest Service, US Dept. of Agriculture, US.

Bell, R. H. V. (1970) The use of herb layer by grazing ungulates in the Serengeti. Pages 111-124 in A. Watson (ed.) *Animal population in relation to their food resources*. Symposium of British Ecological Society, Blackwell Scientific Publications, Oxford, UK.

Bell, R. H. V. (1971) A grazing ecosystem in the Serengeti. *Scientific American*, 224: 86-93.

Bell, W. J. (1991). *Searching behaviour, the behavioural ecology of finding resources*. Chapman and Hall, London.

Belovsky, G. E. (1981) Food plant selection by a generalist herbivore: The Moose. *Ecology*, 62 (4): 1020-1030.

Belsky, A. J. (1986) Does herbivory benefit plants? a review of the evidence. *The American Naturalist*, 127: 870-892.

Ben-Shahar, R. & Skinner, J. D. (1988) Habitat preference of African ungulates derived by uni- and multivariate analysis. *Ecology*, 69: 1445 - 1451.

Ben-Shahar, R. (1990) Resource availability and habitat preference of three African ungulates. *Biological conservation*, 54: 357-365.

Berger, J (1985) Interspecific Interactions and Dominance among Wild Great Basin Ungulates. *Journal of Mammalogy*, 66 (3), 571-573.

Bergman, C. M., Fryxell, J. M., Gates, C. C. & Fortin, D. (2001) Ungulate foraging strategies: energy maximizing or time minimizing? *Journal of Applied Ecology*, 70: 289-300.

Bergman, C. M., Schaeffer, J. A. & Luttich, S. N. (2000). Caribou movement as a correlated random walk. *Oecologia*, 123: 364–374.

Berwick (1974) *The community of wild ruminants in Gir ecosystem*. PhD dissertation, Yale University, U.S.

Bhat, S. D. (1993) *Habitat use by Chital (Cervus axis) in Dhaulkhand, Rajaji National Park, India*. MSc Thesis. Saurashtra University, Rajkot, India.

Bhatnagar, Y. V. (1997) *Ranging and habitat utilization by the Himalayan ibex (Capra ibex sibirica) in Pin Valley National Park.* PhD thesis. Saurashtra University, Rajkot. India.

Biggins, D. E. & Pitcher, E. J. (1978) Comparative efficiencies of telemetry and visual techniques for studying ungulates, grouse and raptors on energy development lands in southern Montana. *Pecora*, 4: 188-193.

Biswas, S. & Sankar, K. (2002). Prey Abundance and food habits of tigers (*Panthera tigris tigris*) in Pench National park, Madhya Pradesh, India. *Journal of Zoology* (*London*), 256: 411 - 420.

Bobek, B. (1977) Summer food as the factor limiting roe deer population size. *Nature* (*London*), 268: 47 - 49.

Bock, C. E. & Bock, J. H. (1998) Tall grass prairie: remnants and relicts. *Great Plains Research,* 8: 213 -230.

Bonham, C. D. (1989) *Measurements for terrestrial vegetation*. John Wiley & Sons, New York.

Bookhout, T. A. editor (1996) *Research and Management techniques for wildlife and habitats*. Fifth ed., rev. the Wildlife Society, Bethesda, Md. 740pp.

Borkowski, J. & Ukalska, J. (2007) Winter habitat use by red and roe deer in pine-dominated forest. *Forest Ecology and Management*, DOI: 10.1016/j.foreco.2007.09.013

Bosch, O. J. H. (1989) Degradation of the semi arid grasslands of the southern Africa, *Journal of Arid Environments*, 16: 165 -175.

Bowyer, R. T., Van Ballenberghe, V., Kie, J. G. & Maier, J. A. (1999) Birth-site selection by Alaskan moose: maternal strategies for coping with a risky environment. *Journal of Mammalogy*, 80:1070-1083.

Brochu, L.; Caron, L. & Bergeron, J. M. (1988) Diet quality and body Condition of dispersing and resident voles (*Microtus pennsylvanicus*), *Journal of Mammalogy*, 69 (4): 704-710.

Buckland, S. T., Anderson, A. R., Burnham, K. P. & Laake, J. L. (1993) *Distance sampling: Estimating abundance of biological populations*. Champion and Hall, London, 446pp.

Bullock, J. M., Franklin, M. J., Stevenson, J., Silvertown, J., Coulson, S. J., Gregory, S. J. & Tofts, R. (2001) A plant trait analysis of responses to grazing in a long term experiment. *Journal of Applied Ecology*, 38: 253 - 267.

Bunnell, F. L. & Gillingham, M. P. (1985) Foraging Behaviour: Dynamics of dining out. Pages 53-79 in R. J. Hudson & R. G. White, (eds.) *Bioenergetics of wild herbivores*. CRC Press Boca Raton, Florida.

Bunnell, F. L. & Harestad, A. S. (1989) Activity budgets and body weights in mammals: How sloppy can mammals be? *Current Mammalogy*, 2: 245-305.

Burnham, K. P., Anderson, D. R. & Laake, J. D. (1980) Estimation of density from line transect sampling of biological populations, *Wildlife Monograph,* 72: 1-202

Cain, M. L. (1985). Random search by herbivorous insects: a simulation model. *Ecology*, 66: 876 - 888.

Cairns, A. L. & Telfer, E. S. (1980) Habitat use by four sympatric ungulates in boreal mixed wood forest. *Journal of Wildlife Managemen*t, 44(4): 849-857.

Caro, T. (1998) Baseline ecological data and conservation problem. Pages 27-55 in Tim Caro (ed.) Behavioural Ecology and conservation biology Oxford University Press, UK.

Caro, T. M. (1994) Ungulate anti-predator behaviour: Preliminary and comparative data from African Bovids. *Behaviour*, 128: 189 - 228.

Carr, R. (2000). XLStatistics 5.71. XLent Works, Australia. [http://www.deakin.edu.au/~rodneyc/xlstats.htm]

Carson, R. G. & Peek, J. M. (1987) Mule deer habitat selection patterns in North-central Washington. *Journal of Wildlife Management*, 51(1): 46-51.

Caughley, G. & Birch, L. C. (1971) Rate of increase. *Journal of Wildlife Management*, 35: 658- 663.

Caughley, G. & Gunn, A. (1993) Dynamics of large herbivores in desert: kangaroos and caribou. *Oikos*, 67: 47-55.

Caughley, G. & Sinclair, A. R. E. (1994) *Wildlife ecology and management*. Blackwell, Oxford.

Caughley, G. (1976) Wildlife management and dynamics of ungulate population. *Advance Applied Biology*, 1: 183 - 246.

Caughley, G. (1977) *Analysis of Vertebrate Populations*. John Wiley and Sons, London.

Caughley, G. (1980) *Analysis of vertebrate populations* [reprinted with corrections]. A Wiley-Interscience publication. New York.

Champion, H. & Seth, S. (1968) *A revised study of the forest types of India*. Government of India Press, New Delhi.

Charnov, E. L. (1976) Optimal Foraging, the marginal value theorem. *Theoretical Population Biology*, 9: 129-136.

Chaudhary, S. R. (1972) The pinch period. *Chital*, 14(4): 28-33.

Cheatum, E. L. (1949) Bone marrow as an index of malnutrition in deer. *New York State Conservation*, 3:19-22.

Chellam, R. (1993) *Ecology of the Asiatic lion (Panthera leo persica).* PhD thesis. Saurashtra University, Rajkot, India.

Chimere, M., Pradhan, D. & Upadhyay, K. (1986) *Livestock control and grazing management in Bhutan*. Study group “C” report on interaction between livestock and forest including grassland.

Church, D. C. (1976) *Digestive physiology and nutrition of ruminants, Vol.1* – Nutrition. O & B. Books, Corvallis, Oregon. USA.

Church, D. C. (1979) *Digestive physiology and nutrition of ruminants, Vol.2* – Nutrition. O & B. Books, Corvallis, Oregon. USA.

Clutton-Brock, T. H. & Harvey, P. H. (1978a) Inbreeding and dispersal in the great tit. *Nature*, 273: 191-195.

Clutton-Brock, T. H. & Harvey, P. H. (1978b) Mammals, resources and reproductive strategies. *Nature* (London), 273: 191-195.

Clutton-Brock, T. H., Illius, A. W. Wilson, K., Grenfell, B. T., MacColl, A. D. C., & Albon, S. D. (1997) Stability and Instability in Ungulate Populations: An Empirical Analysis. *The American Naturalist,* 149:195-219.

Coe, N. J. (1980) African mammals and savannah habitats. Pages 83-109 in N. J. Coe (ed.) *Habitats and their influences on wildlife*. Endangered Wildlife Trust, Pretoria.

Coe, N. J. Cumming, D. H. & Phillipson, J. (1976) Biomass and production of large African herbivores in relation to rainfall and primary production. *Oecologia* (*Berlin*), 22: 341 - 354.

Cohen,W. E., Drawe, D. L. Bryant, F. C.& Bradley, L. C. (1989b) Observations on white tailed deer and habitat response to livestock grazing in South Texas. *Journal of Range Management*, 42: 361 - 365.

Cohen,W. E., Reiner, R. J., Bryant, F. C, Drawe, D. L; Bradley, L. C (1989a) Daytime activity of white-tailed deer in response to short-duration and continuous grazing. *The Southwestern Naturalist*, 34 (3): 428-431.

Colins, W. B. & Urness, P. J. (1981) Habitat preference of mule deer as rated by pellet-group distribution. *Journal of Wildlife Management,* 45: 969-972.

Collins, S. L. (1987) Interaction of disturbances in tall grass prairie: a field experiment. *Ecology,* 68: 1243 -1250.

Cook, C. W. (1959) The effect of site on the palatability and nutritive content of seeded wheatgrasses, *Journal of Range Management*, 12: 289-292.

Cook, R. C., Cook, J. G., Murray, D. L. Zager, P., Johnson, B. K. & Gratson, M. W. (2005) Nutritional condition indices for elk: The good (and less good), the bad, and the ugly. Pages 102-112 in M. J. Wisdom (tech. ed.) *The Starkey Project: a synthesis of long-term studies of elk and mule deer*. Reprinted from the 2004 Transactions of the North American Wildlife and Natural Resources Conference, Alliance Communications Group, Lawrence, Kansas, USA.

Coomes, D. A., Allen, R. B., Forsyth, D. M. & Lee, W. G. (2003) Factors preventing the recovery of New Zealand forests following control of invasive deer. *Conservation Biology* 17: 450–459.

Crawley, M. J. (1983) *Herbivory: The dynamics of animal-plant interactions*. Blackwell, Osney Mead, Oxford.

Crist, T. O., Guertin, D. S., Wiens, J. A. & Milne, B. T. (1992). Animal movement in heterogeneous landscapes: An experiment with *Eleodes* beetles in short-grass prairie. *Functional Ecology*, 6: 536–544.

Cumming, H. M. & Cumming, G. S. (2003) Ungulate community structure and ecological processes: body size, hoof area and trampling in African savannas. *Oecologia,* 134: 560-568.

Datta, A. (1993) *Space use patterns of the Indian Giant Squirrel (Ratufa indica) in Bori Wildlife Sanctuary, M. P., India*. MSc Thesis. Saurashtra University, Rajkot.

Daubenmire, R. F. (1968) *Pant communities: a textbook of plant synecology*. Harper & Row Publication, New York.

De Rames, C. & Spillet, J. (1966) A study of the chital or spotted deer in Corbett National Park, U.P. *Journal of Bombay Natural History Society*, 63 (3): 577-589.

Desai, J. R. (1972) The Gir forest reserve: it' habitats, faunal and social problems. In: Proceedings *Gir Lion Research Seminar*, 193-198.

Detling, J. K. (1998) Mammalian herbivores: ecosystem-level effects in two grassland national parks. *Wildlife Society Bulletin*, 26: 438-448.

Dietz, D. R. (1968) Animal production and forage quality: Definition and components of forage quality. Pages 1-9 in R*ange and Wildlife Habitat*

Evaluation: A Research Symposium. Miscellaneous Publication of Forest Service. US Department of Agriculture. US.

Dinerstein, E. (1979) An ecological survey of Royal Karnali Bardia Wildlife Researve, Nepal. Part-III. Habitat-animal interactions. *Biological Conservation*, 16: 265 - 300.

Dinerstein, E. (1980) An ecological survey of Royal Karnali Bardia Wildlife Reserve, Nepal. Part-III. Ungulate Populations. *Biological Conservation,* 18: 5 - 38.

Dinerstein, E. (1987) Deer, plant phenology, and succession in the lowland forests of Nepal. Pages 272-288 *in* Christen M. Wemmer (ed.) *Biology and Management of the Cervidae*. Smithsonian Institution Press, Washington, DC.

Doergeloh, W. G. (1998) Habitat selection of a roan antelope (*Hippotragus equinus*) population in Mixed Bushweld, Nylsvlei Nature Reserve. *South African Journal of Wildlife Research*, 28(2): 47 - 57.

Dove, H. (1996) The ruminant, the rumen and the pasture resource. Pages 219-245 in J. Hodgson and A. W. Illius (eds.) *The ecology and management of grazing systems*. CAB International Publication, UK.

Droege, S. (1990) The North American Breeding Bird Survey. Pages 1-4 in J. R. Sauer and S. Droege, (eds.) *Survey designs and statistical methods for the estimation of avian population trends*. U.S. Fish Wildlife Service Biology Report, 90(1).

Dublin, H. T., Sinclair, A. R. E. Boutin, S. Anderson, M. & Arcese. P. (1990) Does competition regulate ungulate populations? Further evidence from Serengeti. Tanzania. *Oecologia (Berlin),* 82: 283-288.

Dufrene, M. & Legendre, P. (1997) Species assemblages and indicator species: the need for a flexible asymmetrical approach. *Ecological Monographs*, 67(3): 345-366.

Duncan, P. (1983) Determinants of the habitat by horses in a Mediterranean wetland. *Journal of Animal Ecology*, 52: 93-109.

Dyksterhuis, E. J. (1949) Condition and management of rangeland based on quantitative ecology. *Journal of Range Management,* 2:104-115.

Eberhardt, L. L. & Simons, M. A. (1992) Assessing rates of increase from trend data. *Journal of Wildlife Management*, 56: 603-610.

Eberhardt, L. L. (1987) Population projections from simple models. *Journal of Applied Ecology*, 24: 103-118.

Eisenberg, J. & Siendensticker (1976) Ungulates in Southern Asia: A consideration of biomass estimates for selected habitats. *Biological Conservation*, 10: 293-308.

Eisenberg, J. F. & Lockhart, M. (1972) An ecological reconnaissance of Wilpattu National Park, Ceylon. *Smithsonian contribution to Zoology*, 101: 1-118.

Eisenberg, J. F. (1981) *The Mammalian Radiations: an analysis of trends in evolution, adaptation and behaviour*. The Athlone Press, London.

Ellerman, J. & Morrison-Scott, T. (1951) *Checklist of Palaearctic and Indian mammals, 1758 to 1946*. British Museum, London.

Ellis, J. E. & Swift, D. M. (1988) Stability of African pastoral ecosystems: alternate paradigms and implications for development. *Journal of Range Management*, 41: 450 - 459.

Ellison, L. (1960) Influence of grazing on plant succession of rangelands. *Botanical Review*, 26: 1 - 78.

Eltringham, S. K. (1974) Changes in the large mammal community of Mweya Peninsula, Rwenzori National Park, Uganda, following removal of hippopotamus. *Journal of Applied Ecology*, 11: 855 - 865.

Emlen, J. M. (1966) The role of time and energy in food preference. T*he American Naturalist*, 100: 611 - 617.

Emlen, J. M. (1984) *Population Biology: the coevolution of population dynamics and behaviour*. Mac Milan Publishing Co. New York.

Fancy, S. G., & White, R G. (1985) Incremental cost of activity. Pages 143-159, in R. J. Hudson & R. G. White, (eds.) *Bioenergetics of wild herbivores*. CRC Press, Boca Raton, Florida.

Fensham, R. J., Holeman, J. E. & Cox, M. J. (1999) Plant species responses along a grazing disturbance gradient in Australian grassland. *Journal of Vegetation Science*, 10: 77 - 86.

Fisler, G. F. (1977) Interspecific hierarchy at an artificial food resource. *Animal Behaviour*, 25: 240-244.

Fleischner, T. L. (1994) Ecological costs of livestock grazing in western North America**.** *Conservation Biology*, 8 (3): 629 - 644.

Flook, D. R. (1970) Causes and implications of an observed sex differences in the survival of wapiti. *Canadian Wildlife Service Report Series*, 11: 1 - 71.

Focardi, S., Marcellini, P. & Montanaro, P. (1996) Do ungulates exhibit a food density threshold? A field study of optimal foraging and movement patterns. *Journal of Animal Ecology*, 65: 606 - 620.

Forbes, E. B., Marcy, L. F., LeRoy Voris, A., French, C. E. (1941) The capacities of the white-tailed deer. *Journal of Wildlife Management*, 5(1): 108 -114.

Frank, D. A. & Groffman, P. M. (1998) Ungulate vs. landscape control of soil C and N processes in grasslands of Yellowstone National Park. *Ecology* 79: 2229 - 2241.

Franklin, J. F., Cromack, K. Jr., Denison, W. McKee, A. Maser, C. Sedell, J. Swanson, F.& Juday, G.(1981) *Ecological characteristics of old-growth Douglas-fu forests*. General Technical Report PNW-118. U.S. Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Fretwell, S. D. & Lucas, H. L. (1970) On territorial behaviour and other factors influencing habitat distribution in birds: I. Theoretical development. *Acta Biotheoretica*, 19: 16 - 36.

Fryxell, J. A. (1987) Food limitation and demography of a migratory antelope, the white-eared kob. *Oecologia (Berlin)*, 72: 83 - 91.

Fuchs, E. R. (1977) Behavior. Pages 24-52 in E. D. Ables (ed) *The Axis Deer in Texas,* Texas Caesar Kleberg.

Fusco, M., Holechek, J., Tembo, A., Daniel, A. & Cardenas, M. (1995) Grazing influences on watering point vegetation in the Chihuahuan desert. *Journal of Range Management*, 48: 32 - 38.

Garrison, G. A. (1953) Effects of clipping on some range shrubs. *Journal of Range Management*, 6(5): 309 - 317.

Gaulin, S. J. C. (1979) A Jarman/Bell model of primate feeding niches. *Human Ecology,* 7: 1 - 20.

Gavin, P. (1991) Why ask 'why': the importance of evolutionary biology in wildlife science. *Journal of wildlife management*, 55: 760 - 766.

Gayot, M., Henry, O., Dubost, G. & Sabatier, D. (2004) Comparative diets of two forest cervids of the genus Mazama in French Guiana. *Journal of Tropical Ecology*, 20: 31 - 43.

Geist, V. (1974) On the relationship of social evolution and ecology in ungulates. *American Zoologist*. 14: 205 - 220.

Gerrodette, T. (1987) A power analysis for detecting trends. *Ecology*, 68: 1364 - 1372.

Ghosh, P. K. Goyal, S. P. & Bohra, H. C. (1987) Competition for resource utilization between wild and domestic ungulates in the Rajasthan Desert. *Tiger Paper*, 14: 2 - 7.

Giles, R. H. (1978) *Wildlife Management*. W.H. Freeman & Company. 416pp.

Gillen, R. L., Krueger, W. C. & Miller, R. F. (1984) Cattle distribution on mountain rangeland in northeastern Oregon. *Journal of Range Management*, 37: 549 - 553.

Gillingham, M. P. & Bunnell, F. L. (1989) Effects of learning on food selection and searching behaviour of deer. *Canadian Journal of Zoology*, 67: 24 - 32.

Goering, H. K. & Van Soest, P. J. (1970) *Forage fiber analyses*. Agricultural Handbook No. 379, Govt. Print. US.

Gordon, I. J. & Illius, A. W. (1988) Incisor arcade structure and diet selection in ruminants. *Functional Ecology*, 2: 15 - 22.

Gordon, I. J. & Illius, A. W. (1989) Resource partitioning by ungulates inthe Isle of Rhum. *Oecologia,* 79: 383 - 389.

Gordon, I. J. & Illius, A. W. (1996) The nutritional ecology of African ruminants: a reinterpretation. *Journal of Animal Ecology*, 65:18 - 28.

Gordon, I. J. (1988) Facilitation of red deer grazing by cattle and its impact on red deer performance. *Journal of Applied Ecology*, 25: 1 - 10.

Gordon, I. J. (1989) Vegetation community selection by ungulates on the Isle of Rhum. III. Determinants of vegetation community selection. *Journal of Applied Ecology,* 26: 65 - 79.

Goss-Custard, J. D. & Sutherland, W. J. (1997) Individual behaviours, populations and conservation. Pages 373-379 in Krebs J. R. & Davies, N. B. (eds.) *Behaviour Ecology: an evolutionary approach*, 4th edition. Oxford: Blackwell Scientific.

Gosz, J. R., Likens, G. E. & Bormann, F. H. (1972) Nutrient contents of litter fall on the Hubbard Brook Experimental forests. *Ecology*, 53(5): 769-784.

Gotelli, N. J. & Entsminger, G. L. (2006) *EcoSim: Null models software for ecology. Version 7*. Acquired Intelligence Inc. & Kesey-Bear. Jericho, VT 05465. http://garyentsminger.com/ecosim.htm.

Govt. of Gujarat (1975) Junagadh District. *Gazetteers of Gujarat*. In S. B. Rajyagor (ed.) Government of Gujarat, 848 pp.

Govt. of India (1972) *Wildlife (Protection) Act, 1972*, Ministry of Law & Justice (Legislative Department), Government of India, New Delhi, India.

Goyal, S. P., Mukherjee, S., Qureshi, Q, Sankar, K.,Shah, N., Dave, C. & Zala, Y. P. (2004) *Monitoring Ungulates (Relative abundance and density estimation).* Pages 15-35 In: Y. V. Jhala (ed), *Monitoring of Gir*. A technical report submitted to the Gujarat Forest Department, under the GEF- India Ecodevelopment Program. Wildlife Institute of India, Dehradun.

Graff, W. & Nichols, L. (1966) The Axis deer in Hawaii. *Journal Bombay Natural History Society*, 63: 629-734.

Green, D. M. & Kauffman, J. B. (1995) Succession and livestock grazing in a northeastern Oregon riparian ecosystem. *Journal of Range Management,* 48: 307 - 313.

Green, M. J. B. (1985) *Aspects of the ecology of the musk deer*. PhD Thesis. University of Cambridge, UK.

Green, M. J. B. (1987) Ecological separation in Himalayan ungulates. *Journal of Zoology (London)*, 1: 693 - 719.

Grime, J. P. 1973. Competitive exclusion in herbaceous vegetation. *Nature*, 242: 344 - 347.

Gross, J. E., Zank, C., Hobbs, N. T. & Spalinger, D. E. (1995). Movement rules for herbivores in spatially heterogeneous environments: responses to small scale pattern. *Landscape Ecology*, 10, 209 - 217.

Grubb, P. J. (1986) Problems posed by sparse and patchily distributed species in species rich plant communities. Pages 207-225 in J. Diamond & T. J. Case, eds. Community Ecology. Harper & Row, New York.

Gwyne, M. O. & Bell, R. H. V. (1968) Selection of grazing components by grazing ungulates in the Serrengeti National Park. *Nature (London)*, 220: 390 - 393.

Halls, L. K. (1984) *White Tailed Deer: Ecology and Management*. Stack pole Books.

Haneley, T. A. (1982) The nutritional basis for food selection by ungulates. *Journal of Range Management*, 35(2):146 -158.

Hanley, T. A. & Brady, W. W. (1977) Seasonal fluctuation in nutrient content of feral burro forages, Lower Colorado. *Journal of Wildlife Management*, 41: 70 - 80.

Hanley, T. A. (1984) Habitat patches and their selection by wapiti and black-tailed deer in a coastal montane coniferous forest. *Journal of Applied Ecology*, 21: 423 - 436.

Hansen, R. M. (1976) Foods of free roaming horses in the southern New Maxico. *Journal of Rangeland Management*, 29(4):347.

Hansen, R. M., & Reid, L. D. (1975) Diet overlap of deer, elk and cattle in southern Colorado. *Journal of Rangeland Management*, 26: 43 - 50.

Hansen, R. M., Clark, R. C. & Lawhorn, W. (1977) Food of wild horses, deer and cattle in the Douglas mountain area, Colorado. *Journal of Rangeland Management*, 30: 116 -134.

Hanson, W. O. & Smith, J. G. (1968) Animal Production and Forage Quality: Significance of forage quality as a tool in wildlife management. Pages 25-31 in *Range and Wildlife Habitat Evaluation: A Research Symposium*. Miscellaneous Publication of Forest Service. U. S. Dept. of Agriculture.

Haque, N. (1990) *Study on the ecology of wild ungulates of Keoladeo National Park, Bharatpur, Rajasthan*. PhD Thesis. Center of Wildlife and Ornithology, Aligarh Muslim University, Aligarh, India.

Harder, J. D. & Kirkpatrick, R. L. (1996) Physiological methods in wildlife research. Pages 275-306 in T.A. Bookhout (ed) *Research and Management Techniques for Wildlife and Habitats*. 5th Edition. The Wildlife Society, Bethesda, MD.

Harlow, R. F. (1977) A technique for surveying deer forage in the southeast. *Wildlife Society Bulletin*, 5: 185-191.

Harper, J. L. (1987) The heuristic value of ecological restoration. Pages 35–45 in W. R. Jordan III, M. E. Gilpin, and J. D. Aber (eds.) *Restoration ecology: a synthetic approach to ecological research*. Cambridge University Press, Cambridge, United Kingdom.

Harrington, R. A., Fownes, J. H., Meinzer, F. C. & Scowcroft, P. G. (1995) Forest growth along a rainfall gradient in Hawaii: *Acacia koa* stand structure, productivity, foliar nutrients, and water and nutrient use efficiencies. *Oecologia (Berlin),* 102: 277 - 284.

Harris, R. B. (1986) Reliability of trend lines obtained from variable counts. *Journal of Wildlife Management,* 50: 165 -171.

Hayes, G. E. & Holl, K. D. (2003) Cattle grazing impact on annual forbs and vegetation composition of Mesic grasslands in California. *Conservation Biology*, 17 (6): 1694 -1702.

Heady, H. F. (1964) Palatability of herbage and animal preference. *Journal of Range Management*, 17: 76-82.

Hill, M. O. (1979) *TWINSPAN: A FORTRAN programme for arranging multivariate data in an ordered two-way table by classification of the individuals and attributes*. Ecology and Systematics, Cornell University, Ithaca, New York.

Hirst, S. M. (1969) Road-strip census techniques for wild ungulates in African woodland. *Journal of Wildlife Management*, 33: 40 - 48.

Hobbs, N. T. (1996) Modification of ecosystems by ungulates. *Journal of Wildlife Management* 60: 695 -713.

Hobbs, N. T., Baker, D. L. & Gill, R. B. (1983) Comparative nutritional ecology of montane ungulates during winter. *Journal of Wildlife Management*, 47: 1 -16.

Hobbs, R. J. & Mooney, H. A. (1991) Effects of rainfall variability and gopher disturbance on serpentine annual grassland dynamics. *Ecology*, 72: 59 - 68.

Hobbs, R. J., &. Huenneke, L. F (1992) Disturbance, diversity, and invasion: Implications for conservation. *Conservation Biology,* 6: 324 - 337.

Hodd, K. T. B. (1970) The ecological impact of domestic stocks on the Gir forest. Pages 259-265 in H. F. I. Elliot (ed.) *Eleventh technical meeting. IUCN Publications new series No. 17*. IUCN, Morges, Switzerland.

Hofmann, R. R. (1985) Digestive physiology of the deer and their morphophysiological specialization and adaptation. *The Royal Society of New Zealand Bulletin*, 22: 393 - 407.

Hofmann, R. R. & Stewart, D. R. M. (1972) Grazer or browser: a classification based on the stomach-structure and feeding habits of East African ruminants. *Mammalia,* 36: 226 - 240.

Hofmann, R. R. (1973). The ruminant stomach: Stomach structure and feeding habits of East African game ruminants. *East African Monographs in Biology,* 2: 13 - 54.

Hofmann, R. R. (1989) Evolutionary steps of ecophysiological adaptation and diversification of ruminants: a comparative view of their digestive system. *Oecologia,* 78: 443 - 457.

Holecheck, J. L., Valdez, R. Schemnitz, S. D., Pieper, R. D. & Davis, C. A. (1982) Manipulation of grazing to improve or maintain wildlife habitat. *Wildlife Society Bulletin*, 10 (3): 204 -210.

Holt, R. D. (1987) On the relationship between niche overlap and competition: the effect of incommensurable niche dimensions*. Oikos,* 48:110-114.

Homewood, K. M. (1978). Feeding strategy of the Tana mangabey *(Cercocebus galeritus galentus)* (Mammalia: Primates). *Journal of Zoology*, 186: 375 - 391.

Hone, J. (1999) On rate of increase (r): patterns of variation in Australian mammals and the implications for wildlife management. *Journal of Applied Ecology*, 36: 709-718.

Howard, D. (1982) *Status Report: Wildlife damage to forests in the Vancouver forest region*. WHR-3, Ministry of Forests, Victoria, BC.

Howe, H. F. (1999) Dominance, diversity and grazing in tall grass restoration. *Ecological Restoration*, 17: 59 - 65.

Hubbard, R. L. & Sanderson, H.R. (1960) *Herbage production & carrying capacity of bitterbrush*. General Technical Report. Pacific Southwest Research Station Publication, US Forest Service. US.

Huismann (1997) *The Struggle for Light*. Ph.D. Thesis. University of Groningen, The Netherlands.

Humphrey, R. R. (1949) Field comments on the range condition method of forage survey**.** *Journal of Range Management*, 2 (1): 1 -10.

Hunter, R. F. (1962) Hill sheep and their pasture: A study of sheep grazing in southern east Scotland. *Journal of Ecology*, 50: 651 - 731.

Hurlbert S. H. (1978) The measurement of niche overlap and some relatives. *Ecology,* 59: 67 - 77.

Hurlbert, S. H. (1984) Pseudoreplication and the design of ecological field experiments. *Ecological Monographs*, 54: 187–211.

Illius, A. W. & Gordon, I. J. (1987) The allometry of food intake in grazing ruminants. *Journal of Animal Ecology,* 56: 989 - 999.

Illius, A. W. & Gordon, I. J. (1990) Constraints on diet selection andforaging behaviour in mammalian herbivores. Pages 369-393 in R. N. Hughes (ed.) B*ehavioural Mechanisms of Food Selection*. Springer Verlag, Berlin.

Illius, A.W. & Gordon, I. J. (1993) Diet selection in mammalian herbivores: constraints and tactics. Pages 157-181 in R. N. Hughes (Ed.), *Diet Selection: An Interdisciplinary Approach to Foraging Behaviour*. Blackwell, Oxford.

Illius, A. W. & O'Connor, T. G. (2000) Resource heterogeneity and ungulate population dynamics. *Oikos,* 89: 283 -294.

Isvaran, K. (1995) *A study of lekking in Blackbuck (Antelopa cervicapra) in Velavadar National Park, Gujarat.* MSc Thesis. Saurashtra University, Rajkot, India.

Ivlev, V. S. (1961) *Experimental Ecology of the feeding of fishes.* Yale University Press, New Haven, Conn., US.

Jackson, J. E. (1974) *The feeding ecology of fallow deer in the New Forest*. PhD Thesis, University of Southampton, UK.

James R. Gosz, Likens, G. E., Bormann, F. H. (1975) Nutrient contents of litter fall on the Hurbard Brook experimental forests. *Ecology*, 53 (5): 769 - 784.

James, C.D., Landsberg, J. & Morton, S.R. (1999) Provision of watering points in the Australian arid zone: a review of the effects on biota. *Journal of Arid Environments*, 41: 87 -121.

Jameson, D. A. (1963) Responses of individual plants to harvesting. *Botanical Review*, 29: 532 - 594.

Jameson, D. A. (1970) Land management policy and development of ecological concepts. *Journal of Range Management*, 23: 316 - 321.

Jarman, M. V. & Jarman, P. J. (1973) Daily activity of impala. *East African Wildlife Journal*, 11: 75-92.

Jarman, P. & Sinclair, A. R. (1979) Feeding strategy and the pattern of resource partitioning in ungulates. In: A. R. E. Sinclair & M. Northern Griffith (eds.) *Serengeti: Dynamics of an Ecosystem*. The University of Chicago Press, Chicago.

Jarman, P. J. (1972) Seasonal distribution of large mammal populations in the unflooded middle Zambezi Valley. *Journal of Applied Ecology*, 9: 283 - 299.

Jarman, P. J. (1974) The social organization of antelopes in relation to their ecology. *Behaviour* 48: 215 - 266.

Jenkins, K. J. & Wright, R. G. (1988) Resource partitioning and competition among cervids in Northern Rocky Mountains. *Journal of Applied Ecology*, 25:11 - 24.

Jethva, B. D., & Jhala, Y. V. (2004) Foraging ecology, economics and conservation of Indian wolves in the Bhal region of Gujarat, Western India. *Biological Conservation*, 116: 351 - 357.

Jhala, Y. (1991) *Habitat and population dynamics of wolves and blackbuck in Velavadar National Park, Gujarat, India*. PhD dissertation. Virginia Polytechnic Institute and State University, Blacksburg, Virginia.

Jhala, Y. (1993) Predation on blackbuck by wolves in Velavadar National Park, Gujarat, India. *Conservation Biology*, 7(4): 874 - 881.

Jhala, Y. (1997) Seasonal effects on the nutritional ecology of blackbuck (*Antelopa cervicapra*). *Journal of Applied Ecology,* 34: 1348 -1358.

Jhala, Y., Chellam, R., Qureshi, Q, Pathak, B., Meena, V., Dave, C., Chauhan, K., Benerjee, K. (2006) *Social organization and dispersal of Asiatic lions and Ecological monitoring of Gir.* Technical Report. Wildlife Institute of India, Dehradun.

Johnsingh, A. J. T. & Sankar, K. (1991) Food plants of chital, sambar and cattle on Mundanthurai plateau, South India. *Mammalia,* 55: 57 - 66.

Johnsingh, A. J. T. (1983) Large mammalian prey-predators in Bandipur. *Journal of Bombay Natural History Society*, 80(1):1 - 57.

Johnsingh, A. J. T. & Shankar, K. (1991) Food habits of Chital, Sambar and cattle on Mundantharai plateau, Tamil Nadu, S. India. *Mammalia*, 55(1): 57 - 66.

Johnson, D. H. (1994) Population Analysis. Pages 419-444 in T.A. Bookhout (ed) *Research and Management Techniques for Wildlife and Habitats*. 5th Edition. The Wildlife Society, Bethesda, MD.

Johnson, D. H. (1980) The comparison of usage and availability measurements for evaluating resource preference. *Ecology*, 61:65 - 71.

Johnsoton, A., Bezeau, L. M. & Smoliak, S. (1968) Chemical composition and in vitro digestibility of alpine tundra plants. *Journal of Wildlife Management*, 32: 773 - 777.

Jones, M. E. & Barmuta, L. A. (1998) Diet overlap and relative abundance of sympatric dasyurid carnivores: a hypothesis of competition. *Journal of Animal Ecology*, 67: 410 - 421.

Joslin, P. (1973) *Asiatic Lion: A study of ecology and behaviour*. PhD thesis. University of Edinberg. UK.

Karanth, K. U. & J. D. Nichols (2000) *Ecological status and conservation of tigers in India*. Final technical report to the Division of International Conservation, US Fish and Wildlife Services. US.

Karanth, K. U. & Sinquist, M. E. (1992) Population structure, density and biomass of large herbivores in tropical forests of Nagarhole of India. *Journal of Tropical Ecology*, 8: 21 - 35.

Karanth, U. & Stith, B. M. (1999) Prey depletion as a critical determinant of tiger population viability. Pages 100-113 in J. Seidensticker, S. Christie, and P. Jackson, (eds.) Riding the Tiger. Cambridge University Press. Cambridge, UK.

Karanth, K. U. & Sunquist, M. E. (1995) Prey selection by tiger, leopard and dhole in tropical forests. *Journal of Animal Ecology,* 64(4): 439 - 450.

Karanth, K.U. & Nicholas, J.D. (2002) Monitoring tigers and their preys: a manual for researchers, managers, and conservationists in Tropical Asia. Center for Wildlife Studies, Bangalore, India.

Kareiva, P. & Odell, G. (1987). Swarms of predators exhibit “preytaxis” if individual predators use area-restricted search. *The American Naturalist,* 130: 233 - 270.

Karki, J. B., Jhala, Y. V. & Khanna, P. P. (2000) Grazing lawns in Terai grasslands, Royal Bardai National Park, Nepal. *Biotropica*, 32(3): 423 - 429.

Khan, J. A. (1993) *Ungulate habitat relationships in Gir Ecosystem and it’s management. Implications*. Center of Wildlife and Ornithology. PhD Thesis. Aligarh Muslim University, Aligarh, India.

Khan, J. A. (1994) Food habits of ungulates in dry tropical forests of Gir lion sanctuary, Gujarat, India. *Acta Theriologica*, 39 (2): 185 -193.

Khan, J. A. (1995) Conservation and Management of Gir Lion Sanctuary and National Park, Gujarat, India, *Biological Conservation*, 73: 183-188

Khan, J. A. (1997) Estimation of ungulate densities by line transect method in Gir Forest, India. *Tropical Ecology*, 38 (1): 63 -72.

Khan, J. A. & Vohra, U. (1992) Group size and group structure of chital. Mammalia, 56: 662 - 665.

Khan, J. A., Chellam, R. & Johnsingh, A. J. T. (1995) Group size & age-sex composition of three major ungulate species in Gir Lion Sanctuary, Gujarat, India. *Journal of Bombay Natural History Society,* 92 (3): 295 - 302.

Khan, J. A., Chellam, R., Rodgers, W. A. & Johnsingh, A. J. T. (1996) Ungulate density and biomass in the tropical dry deciduous forests of Gir, Gujarat, India. *Journal of Tropical Ecology,* 12: 149 -162.

Kie, J. G & Lehmkuhl, J. F. (2001) Herbivory by wild and domestic ungulates in the Intermountain west. *Northwest Science*, 75 (Special issue): 55-61.

Kleiber, M. (1961) *The fire of life: an introduction to animal energetics*. John Wiley, New York, US.

Klein, D. R. & Fairall, N. (1986) Comparative foraging behaviour and associated energetics of impala and blesbok. *Journal of Applied Ecology*, 23: 489 - 502.

Klein, D. R. (1962) Rumen contents analysis as an index to range quality. *Trans North American Wildlife & Natural Resource Conference*, 27: 150-164.

Knapp, A. K., Blair, J. M., Brigs, J. M., Collins, S.L., Hartnett, D.C., Johnson, L.C. & Towne, E.G. (1999) The keystone role of bison in North American tall grass prairie. *Bioscience*, 49: 39 - 50.

Koppen, J. M. (1931) Grundriss der Klimakunde. Berlin: Walter de Grayter.

Kortland, A. (1984) Vegetation research and the “bulldozer” herbivores in tropical Africa. Pages 205-226 in: Sutton, S., Whitmore T.C. &

Chadwick A.C. (Eds). *Tropical Rainforests: Ecology and Management*. Blackwell Scientific Publications, Oxford and Boston.

Kothari, A., Pande, P. Singh, S. & Variava, D. (1989) Management of National Parks and Wildlife Sanctuaries in India. A status Report. Indian Institutes of Public Administration, New Delhi.

Krebs, C. J. (1989) *Ecological Methodology* (1st edition), Harper and Row, Publishers, New York.

Krebs, J. R. (1978) Optimal foraging: decision rules for predators. Pages 91-121 in J. R. Krebs & N. H. Davies (eds.) *Behaviour Ecology: an evolutionary approach* (2nd edition). Blackwell Scientific Publishers, Oxford.

Kumar, N. S. (2000). *Ungulate density and biomass in the tropical semi-arid forest of Ranthambore, India.* MSc thesis, Pondicherry University.

Laake, J. L., Buckland, S. T., Anderson, D. R. & Burnham, K. P. (1999) DISTANCE: *User's guide*. Colorado Co-operative Fish and Wildlife Research Unit. Colorado State University, Fort Collins. Colorado, USA.

Lal, J. B. (1989) India's Forests: Myth and Reality. Natraj Publishers, Dehradun.

Lamprey, H. F. (1963) Ecological separation of the large species in the Tarangire Game reserve, Tanganyika. *East African Wildlife Journal*, 1: 63 - 92.

Lancea, R. A., Nicholas, J. D. & Pollock, K. H. (1996) Estimating the number of animals in wildlife population. Pages 215-253 *in* T.A. Bookhout (ed), *Research and Management Techniques for Wildlife and Habitats, 5th Edition*. The Wildlife Society, Bethesda, MD.

Latham, J., Staines, B.W. & Gorman, M.L. (1997) Correlations of red (*Cervus elaphus*) and roe (*Capreolus capreolus*) deer densities in Scottish forests with environmental variables. *Journal of Zoology (London)*, 242: 681 - 704.

Leckenby, D. A. 1968. Influence of plant com- munities on wintering mule deer. Proceedings of Western Association of State Game and Fish Community, 48: 201 - 208.

Leader-Williams, N. (1982) Relationship Between a Disease, Host Density and Mortality in a Free-Living Deer Population. *The Journal of Animal Ecology*, 51:235 -240.

Leopold, B. D., Krausman, P. R. & Hervert, J. J. (1984) Comment: the pellet-group census tech- nique as an indicator of relative habitat use. *Wildlife Society Bulletin*, 12: 325 - 326.

Leuthold, W. (1970) Preliminary observations on the food habits of Gerenuk in Tsavo National Park, Kenya. *East African Wildlife Journal*, 8: 73-84.

Leuthold, W. (1977) *African Ungulates: a comparative review of their ethology and behavioural ecology*. Springer -Verlag, Berlin.

Lever, C. (1985) Naturalized animals of the world. Longman, London. 467 pp.

Linton, L. R., Davies, R. W. & Wrona, F. J. (1981) Resource utilization indices: an assessment. *Journal of Animal Ecology*, 50: 283 - 292.

Litvaitis, J. A., Sherburne, J. A. & Bissonette, J. A. (1985) A comparison of methods used to examine the snowshoe hare habitat use. *Journal of Wildlife Management*, 49: 693 - 695.

Litvaitis, J. A., Titus, K. & Anderson E. M. (1996) Measuring vertebrate use of terrestrial habitats and foods. Pages 254-274. *in* T.A. Bookhout (ed) *Research and Management Techniques for Wildlife and Habitats*. 5th Edition. The Wildlife Society, Bethesda, MD.

Lowlor, L. R. & Maynard Smith, J. (1976) The co-evolution and stability of competing species. *The American Naturalist,* 110: 79 - 99.

Lucas, J. R. (1987) Foraging time constraint and diet choice. Pages 239-269 in A. C. Kamil, J. R. Krebs and H. R. Pulliam, (eds.) *Foraging Behaviour*. New York Plenum Press, NY.

Mac Arthur, R. H. and Pianka, E. R. (1966) On the optimal use of a patchy environment. *The American Naturalist*, 101: 603 - 609.

Mac Cracken, J. G. & Hansen, R. M. (1981) Diets of domestic sheep and other large herbivores in south- central Colorado. *Journal Range Management*, 34: 242 - 243.

Mackie, R. J. (1970) Range ecology and relations of Mule deer, elk and cattle in the Missouri River Breaks, Montana. *Wildlife Monographs,* 20:1 - 79.

Mackie, R. J. (1978) Impacts of livestock grazing on wild ungulates. *Trans North American Wildlife & Natural Resource Conference*, 43: 462 - 476.

Madhusudan, M. D. (2004) Recovery of wild large herbivores following livestock decline in a tropical Indian wildlife reserve. *Journal of Applied Ecology*, 41: 858 - 869.

Magruder, N. D., French, C. E., McEwen, L. C. & Swift, R. W. (1956) Nutritional requirement of white tailed deer for growth and antler development II, *Experimental results of third year. Agriculture Experiment Station Bulletin*, 628 - 649.

Magurran, A. E. (1988) *Ecological diversity and it's measurement*. Croom Helm.

Mahan, C. A. (1967) Comparative food habits of deer and three classes of livestock. *Journal of Wildlife Management*, 28(4): 798 - 803.

Major, J. T. & Sherburne, J. A. (1987) Interspecific relationships of coyotes, bobcats and red foxes in western Maine. *Journal of Wildlife Management*, 51: 606 - 616.

Mandujano, S. & Gallina, S. (1995) Comparison of deer censusing methods in tropical dry forest. *Wildlife Society Bulletin*, 23 (2): 180 -186.

Mann, J. C. E. & Putman, R. J. (1989) Diet of British sika deer (*Cervus Nippon,* Temmenick) in contrasting environments. *Acta theriologica*, 34: 97 - 110.

Mann, J. C. E. (1983) *The social organization and ecology of Japanese sika deer* (*Cervus nippon) in southern England*. PhD thesis, University of Southampton. UK.

Mann, J. C. E. & Putman, R. J. (1989) Diet of British sika deer (*Cervus Nippon,* Temmenick) in contrasting environments. *Acta theriologica*, 34: 97-110.

Marell, A., Ball, J. P. & Hofgaard, A. (2002) Foraging and movement paths of female reindeer: insights from fractal analysis, correlated random walks, and levy flights. *Canadian Journal of Zoology*, 80: 8544 - 8565.

Martin, A. C., Zim, H. S. & Nelson, A. L. (1961) American Wildlife and plants: a guide to wildlife food habits. Dover Publication, New York. NY.

Martin, C. (1982) Interspecific relationship between barasingha and axis deer in Kanha MP, India and relevance to management. Pages 299-306 in C. W. Wemmer (ed) *Biology and management of the Cervidae*. Smithsonian Institution Press, Washington, DC.

Mathur, V. B. (1991) Ecological impacts of livestock grazing on wild ungulates in Sariska National Park. *IV International Rangeland Congress*, Montpellier, France, 485 - 488.

Mattson, W. J., Jr. (1980) Herbivory in relation to plant nitrogen content. *Annual Review of Ecology & Systematics,* 11: 119 -161.

Maynard, L. A., Lossoi, J. K., Hintz, H. F. & Warnwe, R. G. (1979) *Animal nutrition*. McGraw-Hill Book Company, New York.

McDonald, R., Webbon, C. & Harris, S. (2000) The diets of stoats (*Mustela erminea*) & weasel (*Mustela nevalis)* in Great Bretain. *Journal of Zoology (London)*, 252: 363 - 371.

McDowell, L. R. (1985) *Nutrition of Grazing Ruminants in Warm Climates*. Academic Press, New York.

McIntyre, N. E. & Wiens, J. A. (1999). Interactions between landscape structure and animal behaviour: the roles of heterogeneously distributed resources and food deprivation. *Landscape Ecology*, 14: 437 - 447.

McLaren, B. E. (1996) Plant-specific response to herbivory simulated browsing of suppressed balsam fir on Isle Royale. *Ecology* 7: 228 - 235.

McNab, B. K. (1963) Bioenergetics of the determination of home range size. *The American Naturalist*, 97:113 -140.

McNab, B. K. (1980) Food habits, energetics and the population biology of mammals. *The American Naturalist*, 116: 106 -124.

McNaughton, S. J. (1976) Serengeti migratory wildebeest: facilitation of energy flow by grazing. *Science*, 191: 92 - 94.

McNaughton, S. J. (1979) Grazing as an optimization process: grass–ungulate relationships in the Serengeti. *The American Naturalist*, 113: 691 - 703.

McNaughton, S. J. (1983) Compensatory plant growth as a response to herbivory. *Oikos,* 40: 329 - 336.

McNaughton, S. J. (1989) Interactions of plants of the field layer with large herbivores. *Symposia of the Zoological Society of London*, 61:29 -51.

McNaughton, S. J. (1990) Mineral nutrition and seasonal movements of African migratory ungulates. *Nature*, 345: 613 - 615.

McNaughton. S. J. (1993) Grasses and grazer, science and management. *Ecological Applications*, 3: 17 - 20.

McNaughton, S. J., Ruess, R. W. & Seagle, S. W. (1988) Large mammals and process dynamics in African ecosystem. *Bioscience*, 38 (11): 794 - 800.

McShea, W. J., Aung, M., Poszig, D., Wemmer, C. and Monfort, S. (2001) Forage, Habitat use, and sexual segregation by a tropical deer (*Cervus eldi thamin*) in a Dipterocarp forest. *Journal of Mammalogy*. 82(3): 848 - 857.

Meena, V., Jhala, Y., Chellam, R. & Pathak, B. (2007) Demography of the Asiatic lions in the Gir forest, India. *Felid Biology and Conservation Conference*, 17-21 Sept. 2007. University of Oxford. Oxford. UK.

Menard, C., Duncan, P., Fleurance, G., Georges, J. Y. & Lila, M. (2002) Comparative foraging and nutrition of horses and cattle in European wetlands. *Journal of Applied Ecology* 39, 120 - 133.

Milchunas, D. G. & Lauenroth, W. K. (1993) Quantitative effects of grazing on vegetation and soils over a global range of environments*. Ecological Monographs* 63: 327 - 366.

Milner, C. & Gwynne, D. (1974) The soay sheep and their food supply. Pages 273-325, in P. A, Jewell, C.Milner & J. Morton Boyd (eds.) Island Survivors: the ecology of soay sheep of St. Kilda. The Athlone Press, University of London.

Milton S., Dean W. R. J., du Plessis, M. A. & Siegfried, W. R. (1994) A conceptual model of arid rangeland degradation. *Bioscience,* 44: 70 - 76.

Milton, S. J. (1988). The effects of pruning on shoot production and basal increment of *Acacia tortilis*. *South African Journal of Botany*, 54: 109 - 117.

Mishra, C. (2001) *High altitude survival: conflicts between pastoralism and wildlife in Trans-Himalayas*. PhD thesis. Wagenigen University, The Netherlands.

Mishra, C. & Rawat, G. S. (1998). Livestock grazing and biodiversity conservation: comments on Saberwal. *Conservation Biology,* 12: 712 - 714.

Mishra, C., Van Wieren, S., Heitkonig, I. & Prins, H. H. T. (2002) A theoretical analysis of competitive exclusion in a Trans-Himalayan large-herbivore assemblage. *Animal Conservation,* 5: 251 - 258.

Mishra, C., Van Wieren, S., Kenter, P, Heitkonig, I. & Prins, H. H. T. (2004) Competition between domestic livestock and wild bharal *Pseudois nayaur* in the Indian Trans-Himalaya, *Journal of Applied Ecology*, 41: 344 - 354.

Mishra, H. R. (1982) the ecology and behaviour of chital (Axis axis) in Royal Chitwan National Park, Nepal. PhD thesis. University of Edinberg, UK.

Mitchell, B., Staines, B. W. & Welch, D. (1977) Ecology of red deer: a research review relevant to their management in Scotland. Institute of Terrestrial Ecology, Cambridge.

Mitchell, J. (Ed) (1982) *The illustrated reference book of animals*. W. H. Smith & Sons Ltd., England.

Mitchell, J. E. (1983) *Analysis of Forage production for assessment and appraisals*. USDA Forest Service General Technical Report RM-98. Rocky Mountain Forest and Range Experiment station, Fort Collins, Colorado.

Miura, S. (1981) Social behavior of the axis deer during the dry season in Guindy Sanctuary, Madras. *Journal of Bombay Natural History Society*, 78:125 -138.

Moleele, N.M. & Perkins, J.S. (1998) Encroaching woody plant species and boreholes: is cattle density the main driving factor in the Olifants Drift

communal grazing lands, south-eastern Botswana? *Journal of Arid Environments*, 40: 245 - 253.

Moseley, R. K. & Crawford, R. C. (1995) Fifteen year population and habitat changes in Narrow Idaho endemic, *Phlox idahonis* Wherry. *Bulletin of the Torrey Botanical Club*, 122 (2): 109 -114.

Morrison, F. B. (1957) *Feeds and Feeding*. 22nd edition. Morrison Publication Co. Ithaca, New York.

Morse, D. H. (1974) Niche breadth as afunction of social dominance. *The American Naturalist*, 108: 818 - 830.

Mullen, C. A., & Rongstad, O. J. (1979) Evaluation of deer damage to hay in southern Wisconsin. Pages 143 -153 in *American Society for Testing and Materials Special Technical Publication 680,* Philadelphia, US.

Muller-Dombois, D. & Ellenberg, H. (1976) *Aims and Methods in vegetation ecology*. John Wiley and Sons.

Munro, H. N. & Fleck (1969) Analysis of tissues and body fluids for nitrogenous constituents. Pages 423-523 in H. N. Munro (ed.) *Mammalian Protein Metabolism.* Academic Press, New York.

Murden, S. B. & Risenhoover, K. L. (1993) Effect of habitat enrichment on patterns of diet selection. *Ecological Application*, 3: 497-505.

Murray, M. G. & Illius, A. W. (2000) Vegetation modification and resource competition in ungulates. *Oikos,* 89:501–508.

Myers, P., Espinosa, R., Parr, C. S., Jones, T., Hammond, G. S. & Dewey, T. A. (2006) The Animal Diversity Web (online). Accessed May 30, 2007 at http://animaldiversity.org.

Mysterud, A. (2000) Diet overlap among ruminants in Fennoscandia. *Oecologia,* 124:130–137.

Narain, S., Panwar, H. S., Gadgil, M., Thapar, V. & Singh, S. (2005) *Joining the Dots*. The Report of the Tiger Task Force. Project Tiger, Union Ministry of Environment and Forests. New Delhi, India.

National Academy of Sciences- National Research Council (NAS-NRC) (1963) *Nutrient requirement of domestic animals, No. 4 – Nutrient requirements of beef cattle* (3rd edition), NAS- NRC Publication, 1193, 40 pp. Washington D. C.

Newton, P. (1984) *The ecology and Social organization of Hanuman Langurs (Presbytis entellus) in Kanha Tiger Reserve: Central India highland*. PhD Thesis. Wolfson College, Oxford University.

Nott, K. & Savage, M.J. (1985). Observations on utilization of a dune succulent by *Namib faunae*. *South African Journal of Zoology*, 20: 269 - 271.

Noy-Meir, I. (1995) Interactive effects of fire and grazing on structure and diversity of Mediterranean grasslands. *Journal of Vegetation Science*, 6: 701 -710.

Noy-Meir, I., Gutman, M. & Kaplan Y. (1989) Response of Mediterranean grassland plants to grazing and protection. *Journal of Ecology*, 77: 290 - 310.

Orr, C. D. & Dodds, D. G. (1982) Snow shoe hare habitat preference in Nova Scotia spruce –fir forests. *Wildlife Society Bulletin*, 10: 147-150.

Osborne, B.C. (1984) Habitat use by red deer *(Cervus elaphus* L.) and hill sheep in the west highlands. *Journal of Applied Ecology*, 21: 497 - 506.

Owen-Smith, N. & Novellie, P. (1982) What should a clever ungulate eat? *The American Naturalist*, 119:151 - 178.

Owen-Smith, N. (1982) Factors influencing the consumption of plant products by large herbivores. Pages 359-404 in B. J. Huntley & B. H. Walker, (eds.). *The ecology of tropical savannas*. Springer-Verlag, Berlin, Germany.

Owen-Smith, N. (1985) Niche separation among African ungulates. Pages 167–171 in Vrba, E. S. (ed.) *Species and speciation*. Transvaal Museum Monograph, No. 4. Pretoria. S. Africa.

Owen-Smith, N. (1998) How high ambient temperature affects the daily activity and foraging time of a subtropical ungulate, the greater kudu (*Tragelaphus strepsiceros*)? *Journal of Zoology*, 246: 183 -192.

Owen-Smith, N. (2002) Adaptive Herbivore Ecology: From resources to populations in variable environments. Cambridge University Press, Cambridge. UK.

Owen-Smith, N., Mason, D. R. & Ogutu, J. O. (2005) Correlates of survival rates for 10 African ungulate populations: density, rainfall and predation. *Journal of Animal Ecology* 74: 774 - 788.

Owen-Smith, R. N. (1987) Pleistocene extinctions: the pivotal role of megaherbivores. *Paleobiology*, 13: 351 - 362.

Owen-Smith, R. N. (1988) *Megaherbivores: The influence of very large body size on ecology*. Cambridge University Press, Cambridge, United Kingdom.

Park, B. C., & Day, B. B. (1942) A simplified method for determining the condition of white-tailed deer herds in relation to available forage. U.S.D.A. Technical Bulletin, 840: 1 - 60.

Parker, K. L. & Robins, C. T. (1985) Thermoregulations in ungulates. Pages 161-182 in R. J. Hudson and R. G. White, (eds.) *Bioenergetics of wild herbivores*. CRC Press, Boca Raton, Florida, US.

Parker, K. W. (1954) Application of ecology in the determination of range condition and trend. *Journal of Range Management,* 7:14 -23.

Pathak, B. (2002) *Biodiversity Conservation Plan for Gir (A supplementary Management Plan, 2002-03 to 2006-07)*. Wildlife Circle, Junagadh. Gujarat Forest Department.

Perkins, J. S. & Thomas, D. S. G. (1993) Spreading deserts or spatially confined environmental impacts - land degradation and cattle ranching in the Kalahari Desert, Botswana. *Land Degradation and Rehabilitation,* 4: 179 -194.

Petren, K. & Case, T.J. (1998) Habitat structure determines competition intensity and invasion success in gecko lizards. *Proceedings of National Academy Science*, *USA*, 95(20): 11739 -11744.

Pianka, E. R. (1986) *Ecology and Natural history of Desert Lizards*. Princeton University Press, Princeton, NJ.

Pickford, G.D. & Reid, E.H. (1948) *Forage utilization on summer cattle ranges in eastern Oregon*. Circular 796. U.S. Department of Agriculture, US.

Pickup, G. & Chewings, V.H. (1994) A grazing gradient approach to land degradation assessment in arid areas from remotely-sensed data. *International Journal of Remote Sensing*, 15, 597–617.

Powell, T., & P. J. Richerson. (1985) Temporal variation, spatial heterogeneity. and competition for resources in plankton systems: a theoretical model. *The American Naturalist,* 125: 431 - 464.

Prater, S. H. (1971) *The book of Indian animals*. Bombay Natural History Society, Bombay.

Pratt, R. M., Putman, R. J., Ekins, J. R., Edwards, P. J. (1986) Use of habitat by free-ranging cattle and ponies in the New Forest, Southern England. *Journal of Applied Ecology* 23: 539 - 557.

Prins, H. H. T. & Olff, H. (1998) *S*pecies richness of African grazer assemblages: towards a functional explanation. Pages 449-490, D. M. Newbury, H. H. T. Prins & N. D. Brown (eds) *Dynamics of Tropical Communities*. Blackwell, Oxford.

Prins, H. H. T. (1992) The pastoral road to extinction – competition between wildlife and traditional pastoralism in East Africa. *Environmental Conservation,* 19: 117 - 123.

Prins, H. H. T. (2000). Competition between wildlife and livestock in Africa. Pages 51-80 in Prins, H. H. T., Grootenhuis, J. G. & Dolan, T. T. (Eds) *Wildlife conservation by sustainable use*. Boston: Kluwer Academic Publishers, Boston, MA.

Priyadarshini, K. V. R. (2005) *Interactions between forage, recruitment and activity patterns of the India blackbuck* (*Antelopa cervicapra*). PhD thesis, Saurashtra University Rajkot, India.

Puri, G. S., Meher-Homji, V. M. Gupta, R. K. and Puri, S. (1983) *Forest Ecology: Phytogeography and Forest Conservation*. Oxford and IBH Publ. Co. Pvt. Ltd.

Putman, R. J. (1984) Facts from feces. *Mammal Review*. 14: 79 - 97.

Putman, R. J. (1986) Competition and coexistence in a multispecies grazing system. *Acta Theriologica*, 31 (21): 271-291.

Putman, R. J. (1988) *The Natural History of Deer*. Cornell University Press, Ithaca.

Putman, R. J. (1994) *Community Ecology*. Chapman & Hall, London.

Putman, R. J. (1996) *Competition and resource partitioning in temperate ungulate assemblies*. Chapman & Hall, London.

Putman, R. J., Culpin, S. & Thirgood, S. J. (1993) Sexual differences in composition and quality of the diets of male and female fallow deer in sympatry and allopatry. *Journal of Zoology (London)*, 229: 267 - 275.

Putman, R. J., Pratt, R. M., Ekins, J. R. & Edwards, P. J. (1987) Food and feeding behaviour of cattle and ponies in the new forest, Hampshire. *Journal of Applied Ecology,* 24: 369 - 380.

Putman, R. J., Pratt, R. M., Ekins, J. R. & Edwards, P. J. (1984) Patterns of habitat use and grazing by cattle and ponies and impact upon vegetation (Proceedings of the 3rd International Theriological Congress, Helsinki, 1982). *Acta Zoologica Fennica,* 172: 183 - 189.

Pyke, G. H. (1984) Optimal foraging theory: a critical review. *Annual Review of Ecology and Systematics*, 15: 523 - 575.

Qureshi, Q. & Shah, N. (2004) Vegetation and Habitat monitoring. Pages 8-14 in Y.V. Jhala (ed.) *Monitoring of Gir*. A technical report submitted to the Gujarat Forest Department under GEF-India Ecodevelopment Program, Wildlife Institute of India, Dehradun.

Ram Prasad & Bhatnagar, P. (1988) *Grazing in Forests: An ecological liability*. Report no.25. State forest Department Research Institute, Jabalpur, India..

Ramakrishnan, U., Coss, R. G. & Pelkey, N. W. (1999) Tiger decline caused by the reduction of large ungulate prey: evidence from a study of leopard diets in southern India. *Biological Conservation,* 89:113 -120.

Range Inventory Standardization Committee (1983) *Guidelines and terminology for range inventories and monitoring*. Report of the Range Inventory Standardization Committee. Society for Range Management, Denver, Colorado.

Rannestad, O. T., Danielsen, T., Moe, S. & Stokke, S. (2006) Adjacent pastoral areas support higher densities of wild ungulates during the wet season than the Lake Mburo National Park in Uganda. *Journal of Tropical Ecology*, 22: 675 - 683.

Renecker, L. A. and R. J. Hudson. 1993. Morphology, bioenergetics, and resource use: patterns and processes. Pages 141-163 in J. B. Stelfox (ed.) *Hoofed mammals of Alberta*. Lone Pine, Edmonton, Alberta.

Reynolds, R. T. & Meslow, E. C. (1984) Partitioning food and niche characteristics of coexisting *Accipiter* during breeding. *Auk*, 101:761 - 779.

Rhodes, B. D. & Sharrow, S. H. (1990) Effect of grazing by sheep on the quantity and quality of forage available to big game in Oregon coast range. *Journal of Rangeland Management*, 43: 235 -242.

Riginos, C. & Hoffman, M. T. (2003) Changes in population biology of two succulent shrubs along a grazing gradient. *Journal of Applied Ecology*, 40(4): 615 - 625.

Riney, T. (1960) A field technique for assessing physical condition of some ungulates. *Journal of Wildlife Management,* 24: 92 - 94.

Roath, L. R. & Krueger, W. C. (1982) Cattle grazing influence on a mountain riparian zone. *Journal of Range Management*, 35:100 -103.

Robbins, C. T. (1993) *Wildlife feeding and nutrition*, New York Academic Press, New York.

Robbins, C. T. & Moen, A. N. (1975) Composition and digestibility of several deciduous browses in the Northeast. *Journal of Wildlife Management*, 39(2): 337 - 344.

Robbins, C. T., Van Soest, P. J., Mautz, W. W. and Moen, A. N. (1975) Feed analysis and digestion in reference to white tailed deer. *Journal of Wildlife Management*, 39(1): 67 - 77.

Roberts, T. J. (1997) *The Mammals of Pakistan*. Oxford University Press Karachi Pakistan.

Rodgers, W. A. (1988) The wild grazing ungulates of India: An ecological review. Pages 9-12 in P. Singh and P.S. Pathak (eds.) *Rangeland Resources and Management: Proceedings of National Rangeland Symposium*, IGFRI, Jhasi, India.

Rodgers, W. A. (1990) Livestock feeding ecology in forestlands: Methodologies and initial results. *Tropical Ecology*, 31(2): 50 - 58.

Rollinson, D., Harker, K., Taylor, J. & Leech, F. (1956) Studies on the Zebu cattle IV: Errors associated with recording techniques. *Journal of Agriculture Science (Cambridge)*, 47: 1 - 5.

Rongstad, O. & Tester, J. (1969) Movements and habitat use of White tailed deer in Minnesota. *Journal of Wildlife Management*, 33: 366 - 379.

Rooney, T.P., Weigman, S.M., Rogers, D.A. & Waller, D.M. (2004) Biotic impoverishment in unfragmented forest understory communities. *Conservation Biology* 18: 787 - 798.

Rosenzweig, M. L. (1974) On the evolution of habitat selection. Pages 401-404 in Proceedingsof the First International Congress of Ecology. Centre for Agricultural Publishing and Documentation. Wagenngen, Netherlands.

Rosenzweig, M. L. (1979) Optimal habitat selection in two species competitive systems. Pages 283-193 in U. Halbach & J. Jacobs, (eds.) *Population Ecology*. Gustav Fischer Vertag. Stuttgart. West Germany.

Rosenzweig, M. L. (1981) A Theory of habitat selection. *Ecology*, 62: 327 - 335.

Runyoro,V.A., Hofer,H., Chausi, E. B.& Moehlman, P. D. (1995) Long term trends in the herbivore populations of the Ngorongoro crater, Tanzania. Pages 146–168 in Sinclair A. R. E. & Arcese P. (eds.). *Serengeti II: dynamics*, *Management and conservation of an ecosystem*. University of Chicago Press, Chicago.

Ruyle, G. B., Browns, J. E. & Schlundt, A. F. (1983) Estimating snobbery (*Symphoricarpos oreophilus*) utilization by sheep from twig diameter-weight relations. *Journal of Range Management*, 36 (4): 472-474.

Sabarwal, V.K. (1996) Pastoral politics: Gaddi grazing, degradation, & biodiversity conservation in Himachal Pradesh. *Conservation Biology*, 10: 741 -749.

Saberwal, V. K. (1998). Degradation and environmental conservation: response to Mishra and Rawat. *Conservation Biology,* 12: 715 - 717.

Saharia, V. B. (1984) Human dimension in wildlife management: The Indian experience. In Mc Neely and K. R. Milter (eds.) *National Park Conservation and Development*. Smithsonian Institute Press.

Samuel, M. J. & Howard, G. S. (1982) Botanical composition of summer cattle diets on the Wyoming High Plains. *Journal of Range Management*, 35: 305 - 308.

Sankar, K. (1994) *The ecology of three large sympatric herbivores (Chital, Sambar and Nilgai) with special reference for reserve management in Sariska Tiger Reserve, Rajasthan.* PhD Thesis. University of Rajasthan, Jaipur.

Santapau, H. & Raizada, M. B. (1956) contribution to the flora of Gir in Saurashtra. Indian Forester. 40: 105 -170.

Schaller, G. B. (1967) *The deer and the tiger*. University of Chicago Press. USA.

Schmidt-Nielsen, K. (1972) Recent advances in the comparative physiology of desert animals. *Symposium of Zoological Society of London*, 31: 371-382.

Schmidt-Nielsen, K. (1997) *Animal Physiology: Adaptation and Environment*. 5th edition, Cambridge University Press.

Schoener, T. W. (1970) Non-synchronous spatial overlap of lizards in patchy habitats. *Ecology*, 51: 408 - 418.

Schoener, T. W. (1971) Theory of feeding strategies. *Annual Review of Ecology and Systematics*, 2: 369 - 404.

Schoener, T. W. (1974) Resource partitioning in ecological communities. *Science*, 185: 27 - 39.

Schoener, T. W. (1982) The controversy over interspecific competition. *American Scientist*. 70: 586 - 595.

Schwartz, C. C., & Ellis, J. E. (1981) Feeding ecology and niche separation in some native and domestic ungulates on the shortgrass prairie. *Journal of Applied Ecology*, 18: 343 - 353.

Seagle, S. W. & Liang, S. Y. (1997). Bottomland forest composition and seedling diversity: simulations succession and browsing by overabundant deer. In: McShea, W.J., Underwood, H.B., Rappole, J.H

(Eds.), *The Science of overabundance: Deer Ecology and Population Management.* Smithsonian Institution Press, Washington, DC, pp. 346 - 365.

Sekhsaria, P. (2007) Conservation in India and the Need to Think Beyond "Tiger vs. Tribal" *Biotropica*, 39(5), 575-577.

Senft, R. L., Rittenhouse, L. R. & Woodmansee, R. G. (1985) Factors influencing patterns of cattle grazing behaviour on shortgrass steppe. *Journal of Range Management,* 38: 82 - 87.

Senft, R.L., Coughenour, M.B., Bailey, D.W., Rittenhouse, L.R., Sala, O.E. & Swift, D.M., (1987) Large herbivore foraging and ecological hierarchies. *Bioscience* 37: 789 - 799.

Shankar Raman, T. R. (1997) Factors influencing seasonal and monthly changes in the group size of Chital or Axis Deer in S. India. *Journal of Biosciences*, 22(2): 203 - 218.

Shannon, N. H., Hudson, R. J. Brink, V. C. & Kitts, W. D. (1975) Determinants of spatial distribution of mountain bighorn sheep. *Journal of Wildlife Management*, 39 (2): 387 - 401.

Sharatchandra, H. C. & Gadgil, M. (1975) A year of Bandipur. *Journal of Bombay Natural History Society*, 72(3): 623 - 647.

Sharatchandra, H. C. & Gadgil, M. (1980) On the time budget of different life history stages of Chital (*Axis axis*). *Journal of Bombay Natural History Society*, 75 (suppl.): 949 - 960.

Sharma, D. (1995) *Ecology and management of lion and ungulate habitats in Gir.* Ph.D. thesis. Saurashtra University, Rajkot, India

Shea, S., Flynn, B., Marchink, R. & Lewis, J. (1990) *Social behaviour, movement, ecology and food habits of Sambar Deer on St. Vincent. National Wildlife Refuge, Florida.* Bulletin no. 25, Tall Timber Research Station, Tallahassee, Florida

Short, H. L, Blair, R. M. & Segelquist, C. A. (1974) Fibre composition and forage digestibility by small ruminants. *Journal of Wildlife Management*, 38(2):197 - 209.

Short, H. L. & Epps, A. E. (1976) Nutrient quality and digestibility of seeds and fruits from southern forests. *Journal of Wildlife Management*, 40(2): 283 - 287.

Short, H.L. (1975) Nutrition of southern deer in different seasons. *Journal of Wildlife Management*, 39(2): 321 - 329.

Shrestha, S. M. (1982) Habitat and behaviour pattern of chital (spotted deer) with special reference to Nepal, WII, Dehradun.

Sibly, R. M. & Smith, R. H. (1998) Identifying key factors using λ contribution analysis. *Journal of Animal Ecology,* 67: 17 - 24.

Sidensticker, J. (1976) Ungulate population in Chitwan valley, Nepal. *Biological Conservation*, 10: 183 - 210.

Silori, C. & Mishra, B. (2001) Assessment of livestock grazing pressure in and around the elephant corridors in Mundantharai Wildlife Sanctuary. *Biological Conservation*, 10 (12): 2181 - 2195.

Sinclair, A. R. E. (1975) The resource limitation of trophic levels in tropical grassland ecosystems. *Journal of Animal Ecology*, 44: 497 - 520.

Sinclair, A. R. E. (1977) The African Buffalo: A study of resource limitations of population. University of Chicago Press, Chicago and London.

Sinclair, A. R. E., Mduma, S. A. R. & Arcese, P. (2000) What determines phenology and synchrony of ungulate breeding in the Serengeti? *Ecology*, 81: 2100 - 2111.

Sinclair, A. R. E. & Norton-Griffiths, M. (1982) Does competition or facilitation regulate migrant ungulate populations in the Serengeti? *Oecologia (Berlin),* 53: 361-369.

Sinclair, A. R. E. (1979) Dynamics of the Serengeti ecosystem. Pages 1-30 in Sinclair, A. R. E. and Norton-Griffiths, M. (eds.), *Serengeti: dynamics of an ecosystem*. University of Chicago Press, Chicago.

Sinclair. A. R. E. (1985) Does interspecific competition or predation shape the African ungulate community? *Journal of Animal Ecology*, 54: 899 – 918.

Sinclair. A. R. E., Dublin, H. & Borner. M. (1985) Population regulation of Serengeti wildebeest: a test of the food hypothesis. *Oecologia (Berlin),* 65: 266 - 268.

Singh, H. S. & Kamboj, R. D. (1996) *Biodiversity Conservation Plan for Gir (A management plan for Gir Sanctuary and National Park)*. Forest Department, Gujarat State. Vol. I and II.

Singh, H. S. (1997) Population dynamics, group structure and natural dispersal of the Asiatic Lion. *Journal of Bombay Natural History Society*, 94: 65 -70.

Singh, J. S. & Misra, R. (1969) Diversity, dominance, stability and net production in the grasslands at Varansi. *Journal of Canadian Botany*, 47: 425- 427.

Sinha, S. P. (1987) Ecology of wildlife with special reference to the lion (Panthera leo persica) in Gir Wildlife Sanctuary, Saurashtra, Gujarat. PhD thesis. Saurashtra University, Rajkot, India.

Skogland, T. (1980) Comparative summer feeding strategies of arctic and alpine Rangifer. *Journal of Animal Ecology*, 49: 81 - 98.

Skogland, T. (1985) The effects of density-dependent resource limitation on the demography of wild reindeer. *Journal of Animal Ecology*, 54: 359 - 374.

Skogland, T. (1990) Density-dependence in a fluctuating wild reindeer herd; maternal v/s. offspring effects. *Oecologia (Berlin),* 84: 442 - 450.

Smith, E. L. (1979) Evaluation of the range condition concept. *Rangelands*, 1: 52 - 54.

Smith, F. H., Beeson, K. C. & Price, W. E. (1956) Chemical composition of herbage browsed by deer in two wildlife management areas. *Journal of Wildlife Management*, 20(4): 359 - 367.

Spalinger, D. E. & Hobbs, T. (1992) New models of functional response. *The American Naturalist*, 140 (2): 325 - 348.

Spowart, R. A. & Hobbs, T. (1985) Effects of fire on diet overlap between mule deer and mountain sheep. *Journal of Wildlife Management*, 49(4): 942 - 946.

SPSS for Windows, Rel. 8.0.0. 1997. Chicago: SPSS Inc.

Stain, B. W. & Crisp, J. M. (1978) Observations on food quality in Scottish red deer (*Cervus elaphus*) as determined by chemical analysis of nutrient contents. *Journal of Zoology (London)*, 185: 253 - 259.

Steinheim, G., Wegge, P., Fjellstad, J. I., Jnawali, S. R. & Weladji, R. B. (2005) Dry season diets and habitat use of sympatric Asian elephants (*Elephas maximus*) and greater one-horned rhinoceros (*Rhinoceros unicornis*) in Nepal. *Journal of Zoology (London)*, 265: 377 - 385.

Stephenson, T. E., Holechek, J. L. & Kuykendall, C. B. (1985) Diets of four wild ungulates on winter range in north central New Mexico. *The Southwestern Naturalist*, 30(3): 437 – 441.

Stewart, K. M., Bowyer, R. T., Kie, J. G., Dick, B. L. & Ben-David, M. (2003) Niche partitioning among mule deer, elk & cattle: do stable isotopes reflect dietary niche? *Ecoscience*, 10: 297 - 302.

Stinnett, D. P. & Klebenow, D. A. (1986) Habitat use of irrigated lands by California quail in Nevada. *Journal of Wildlife Management*, 50: 368 - 372.

Stuth, J. W. (1991) Foraging behaviour. Pages 65-83 in R.K. Heitschmidt & J.W. Stuth (Eds.), *Grazing Management: An Ecological Approach*. Timber Press, Inc., Portland, Oregon.

Sukh Dev (1978) *Chemical analysis of some chital browse species and digestibility trials on Chital (Axis axis)*. Dissertation, 1st Diploma course in wildlife management. Forest Research Institute and Colleges, Dehradun, India.

Swift, R. W. (1948) Deer select most nutritious forages. *Journal of Wildlife Management*, 12: 109 -110.

Tak, P. C. & Lamba, B. S. (1984) *Ecology and ethology of the spotted deer (Axis axis axis* Erxleben*)*. Records of Zoological Survey of India.

Talbot, L. & Talbot, M. (1962) Food preference of some East African ungulates. *East African Agriculture and Forestry Journal*, 27: 131 -138.

Talbot, M. W. Biswell, H. H. & Hormany, A. L. (1939) Fluctuations in annual vegetation of California. *Ecology*, 20: 394 - 402.

Tansley, A.G. & Adamson, R.S. (1925) Studies of the vegetation of the English chalk. III. The chalk grasslands of the Hampshire-Sussex border. *Journal of Ecology*, 13: 12 -223.

Taylor, C. R. (1972) The desert gazelle: A paradox resolved. *Symposium of Zoological Society of London*, 31: 215 - 227.

Taylor, R. D. & Walker, B. H. (1978) Comparison of vegetation use and herbivore biomass on a Rhodesian game and cattle ranch. *Journal of Applied Ecology* 15: 565–581.

Teague, W. R. (1985) Leaf growth of Acacia karroo trees in response to frequency and intensity of defoliation. Pages 220-222 in J. C. Tothill and J. J. Mott, eds. *Ecology and Management of the World's Savannas*. Australian Academy of Science, Canberra.

Thackeray. J. F. (1980) New approaches in interpreting archaeological faunal assemblages with examples from Southern Africa. *South African Journal of Science*, 76: 216 - 224.

Thill, R. E. & Martin, A. Jr (1986) Deer and Cattle Diet Overlap on Louisiana pine- Bluestem Range. *Journal of Wildlife Management,* 50: 707 - 713.

Thomas, D. L. & Taylor, E. J. (1990) Study designs and tests for comparing the resource use and availability. *Journal of Wildlife Management*, 54: 322 - 330.

Thompson, C.B., Holter, J. B., Hayes, H. H., Silver, H. & Urban, W. E, Jr. (1973) Nutrition of white tailed deer: Energy requirement of fawns. *Journal of Wildlife Management*, 37 (3): 301 - 311.

Thompson, I. D., Davidson, I. J., O'Donnell, S., & Brazeau (1989) Use of track transects to measure the relative occurrence of boreal mammals in uncut and regenerating stands. *Canadian Journal of Zoology*, 67: 1816 - 1823.

Tolsma, D.J., Ernst, W.H.O. & Verwey, R.A. (1987) Nutrients in soil and vegetation around two artificial waterpoints in eastern Botswana. *Journal of Applied Ecology*, 24: 991 - 1000.

Torgerson, O. & Pfander, W. H. (1971) Cellulose digestibility and chemical composition of Missouri deer foods. *Journal of Wildlife Management*, 35: 221 - 231.

Tueller, P. T. (1979) *Food habits and nutrition of Mule deer on Nevada ranges*. Final Report. Nevada Dept. of Fish and Game, Nevada and Nevada Agricultural Experiment Station, University of Nevada- Reno.

Tufto, J., Andersen R. & Linnell, J. D. C. (1996) Habitat use and ecological correlates of home range size in a small cervid: the roe deer. *Journal of Animal Ecology* 65: 715 - 724.

Turchin, P. (1991) Translating foraging movements in heterogeneous environments into the spatial distribution of foragers. *Ecology*, 72: 1253 -1266.

Turchin, P. (1998) *Quantitative analysis of movement*. Sinauer Associates, Sunderland Massachusetts.

Turner, M.D. (1998) Long-term effects of daily grazing orbits on nutrient availability in Sahelian West Africa. II. Effects of a phosphorus gradient on spatial patterns of annual grassland production. *Journal of Biogeography*, 25: 683 - 694.

Twine, W. (2002) Feeding time budgets of selected African ruminant and non-ruminant grazer. *African Journal of Ecology*, 40: 410 - 412.

Uresk, D. (1986) Food habits of cattle on mixed-grass prairie on the northern Great Plains. *Prairie Naturalist*, 18(4): 211 - 218.

Urness, P. J. (1969) Nutritional analysis and invitro digestibility of Mistletoes browsed by Deer in Arizona. *Journal of Wildlife Management*, 33(3): 499 - 505.

Uruess, P. J., Neff, D. J. & Vahle, J. R. (1975) Nutrient contents of Mule deer diets from Ponderosa Pine Range. *Journal of Wildlife Management*, 39(4): 670-673.

Van Dyke, Walter, A., Alan, S. Youkum, J., Alan, P. & Blaisdell, J. (1983) *Wildlife habitats in managed rangelands: The Great Basin of*

southeastern Oregon bighorn sheep. General Technical Report. NHW-19: 1 - 36.

Van Dyne, G. M., Brockington, N. R., Szocs, Z., Duek, J. & Ribic, C.A. (1980) Large herbivore subsystem. Pages 269-537 in Breymeyer, A.I., Van Dyne, G.M. (Eds.), *Grasslands, Systems Analysis and Man*. Cambridge University Press, Cambridge.

Van Rooyen, N., Bredenkamp, G. J., Theron, G. K., Bothma, J., du, P. & le Riche, E.A.N. (1994) Vegetational gradients around artificial watering points in the Kalahari Gemsbok National Park. *Journal of Arid Environments*, 26: 349 - 362.

Van Soest, P. J. (1982) *Nutritional ecology of the ruminant*. Comstock Publishers Associates, Cornell University Press, Ithaca, New York.

Varman, K. S. & Sukumar, R. (1995) The line transect method for estimating density of large mammals in a tropical deciduous forest: An evaluation of models and field experiments. *Journal of Biosciences*, 20: 273 -287.

Vavra, M., & Sheehy, D. P. (1996) Improving elk habitat characteristics with livestock grazing. *Rangelands,* 18:182-185.

Vavra, M., Rice, R. W., Hansen, R. M. & Sims, P. L. (1977) Food habits of cattle on shortgrass range in northeastern Colorado. *Journal of Range Management,* 30: 261 - 263.

Vavra, M., Willis, M. J. & Sheehy, D. (1999) Livestock-big game relationships: conflicts and compatibilities. Pages 130-136 in K.L. Launchbaugh, J.C. Mosley, and K.D. Sanders, (Eds.) *Grazing behavior of livestock and wildlife*. Station Bulletin 70 University of Idaho, Moscow, ID.

Vesey-Fitzgerald, D. F. (1960) Grazing succession among East African game animals. *Journal of Mammalogy*, 41:161 - 172.

Vesey-Fitzgerald, D. F. (1973) *East African grasslands*. East African Publishing House, Nairobi, Kenya.

Viswanathan, G. M., Buldyrev, S. V., Havlin, S., da Luz, M. G., Raposo, E. P. & Stanley, H. E. (1999) Optimizing the success of random searches. *Nature*, 401: 911 - 914.

Voeten, M. M & Prins, H. H. T. (1999) Resource partitioning between sympatric wild and domestic herbivores in the Tarangire region of Tanzania. *Oecologia,* 120: 287 - 294.

Walker, B. H. (1957) Range use, Food habits and agriculture relationships of the Mule deer. *Journal of Wildlife Management,* 39: (2): 699 - 700.

Walker, B. H., Emslie, R. H., Owen-Smith, R. N. & Scholes, R. J. (1987) To cull or not to cull: Lessons from a southern African drought. *Journal of Applied Ecology*, 24: 381 - 401.

Wallace, M.C. & Krausman, P.R. (1987) Elk, mule deer, and cattle habitats in Central Arizona. *Journal of Range Management*, 40 (1): 80 - 83.

Wallmo, O. C. & Neff, D. J. (1970) Direct observation of tame deer to measure their consumption of natural forage. Pages 105-110 in *Range and Wildlife Habitat Evaluation- a Research Symposium*. Miscellaneous Publication No. 1147. USDA and Forest Service. Washington, D.C.

Watkins, W. G., Hudson J. R. & Fargey, P. L. J. (1991) Compensatory growth of wapiti (*Cervus elaphus*) on aspen parkland ranges. *Canadian Journal of Zoology,* 69: 1682 - 1688.

Weins, J. A. (1977) On competition and variable environments. *American Scientist,* 65: 590 - 597.

Weltzin, J. F. & Coughenour, M. B. (1990) Savanna tree influence on understory vegetation and soil nutrients in northwestern Kenya. *Journal of Vegetation Science*, 1: 325 - 334.

Westoby, M., Walker, B. & Noy-Meir, I. (1989) Opportunistic management for rangelands not at equilibrium. *Journal of Range Management*, 42: 266 - 272.

White, T. C. R. (1978) The importance of a relative shortage of food in animal ecology. *Oecologia*, 33: 71 - 86.

Wilson, A. D. (1976) Comparison of sheep and cattle grazing on a semiarid grassland. *Australian Journal of Agriculture research*, 27: 155 -162.

Wilson, E. O. (1975) Sociobiology. The new synthesis. (Cambridge: Belknap Press)

With, K. A., Cadaret, S. J. & Davis, C. (1999). Movement responses to patch structure in experimental fractal landscapes. *Ecology*, 80: 1340 - 1354.

Woolnough, A. P & du Toit, J. T. (2001) Vertical zonation of browse quality in tree canopies exposed to size-structured guild of African browsing ungulates. *Oecologia,* 129: 585 - 590.

Wynter-Blyth, M. A. (1949) The Gir forest and it's lions. *Journal of Bombay Natural history Society*, 48: 493 -513.

Wynter-Blyth, M. A. (1952) Gir forests and it's lions. *Journal of Bombay Natural History Society,* 53: 527-536.

Wynter-Blyth, M. A. (1962) An essay on the geography of Saurashtra. Rajkot, India: Rajkumar College Publications.

Yeo, J.J., Peek, J.M., Wittinger, W.T. & Kvale, C.T. (1993) Influence of rest-rotation cattle grazing on mule deer and elk habitat use in east-central Idaho. *Journal of Range Management*, 46: 245-250.

Yuvraj, J. (1959) The Gir forest and it's lions. *Journal of Bombay Natural history Society*, 38: 153-154.

Zar, J. H. (1984) *Biostatistical Analysis*. Second edition. Prentice Hall, New Jersey.

Zollner, P. A. & Lima, S. L. (1999). Search strategies for landscape-level inter-patch movements. *Ecology*, 80: 1019 -1030.

Appendix - I: List of palatable species consumed by chital, cattle and buffalo in Gir forests.

Plant Species	Local Name	Palatable Parts	Chital	Cattle	Buffalo
Abrus precatorius	Chanothi	Leaves	+		
Acacia catechu	Kher	Leaves & Fruits	+	+	+
Acacia ferrunginia	Babarkher	Leaves		+	
Acacia leucophloea	Harmo	Leaves & Fruits	+	+	+
Acacia nilotica	Bawal	Leaves & Fruits	+	+	+
Achyranthus aspera	Aghedo	Leaves	+		
Aegel marmelos	Bili	Leaves		+	+
Albizia odoratissima	Sarsado	Leaves		+	
Ammannia baccifera	Jarjadvu	Leaves			
Anogeissus latifolia	Dhavdo	Leaves	+	+	+
Apluda mutica	Foflu	Whole plant	+	+	+
Aristida adscensionis	Bhuklo	Whole plant	+	+	+
Arundinella pumila	Nadi	Whole plant		+	+
Asparagus racemosus	Aerusava	Whole plant	+	+	+
Azadirachta indica	Limdo	Leaves		+	
Balanites aegyptica	Ingori	Leaves & Fruits	+		
Barleria hochstetteri	Laho Aselio	Leaves	+	+	+
Barleria priontis	Aselio	Leaves	+	+	+
Bauhinia racemosa	Asundro	Leaves	+	+	+
Blepharis maderaspatensis	Kutelo	Leaves	+	+	+
Borreria stricta	Dhrath	Whole plant	+	+	+
Boswelia serrata	Saledi	Leaves		+	+
Capparis sepiara	Kantharo	Leaves	+	+	+
Carrisa congesta	Karamdi	Leaves	+	+	+
Cassia tora	Kuvadiyo	Dry twigs	+	+	+
Chionachne koenigii	Garolu	Whole plant	+	+	+
Cissus repanda	Gandovelo	Leaves	+	+	+
Clerodendrum multiflorum	Arni	Leaves	+		
Cocculus hirsutus	Vevdi velo	Leaves	+		+
Crotalaria linifolia	Jinjni	Leaves		+	+
Curculigo orchioides	Karli	Leaves			+
Cymbopogon martinii	Rosh	Whole plant		+	+
Cyperus nutans	Saiyo	Whole plant	+	+	+
Datura metel	Dhaturo	Leaves		+	
Desmostachya bipinnata	Daraf	Whole plant		+	+
Dichanthium annulatum	Jinjvo	Whole plant	+	+	+
Dichrostachys cinerea	Madham	Leaves & Fruits	+	+	+
Diospyros melanoxylon	Timru	Leaves	+		+
Echinochloa colonum	Sambo	Whole plant	+	+	+
Ehretia laevis	Vadhvadiyo	Leaves	+		+

Contd…

Plant Species	Local Name	Palatable Parts	Chital	Cattle	Buffalo
Emblica officinalis	Ambali	Leaves	+	+	+
Eragrostis poaeoides	Chakumaku	Whole plant	+	+	+
Eremopogon foveolatus	Shaniyar	Whole plant	+	+	+
Eulophia spp		Flower	+		+
Ficus benghalensis	Vadlo	Fruits	+		
Ficus glomerata	Umaro	Fruits	+		
Ficus religiosa	Pipla	Leaves & Fruits		+	
Flacourtia indica	Ludri	Leaves	+	+	+
Grewia hirsuta	Khad dhraman	Leaves		+	+
Grewia tiliaefolia	Dhraman	Leaves	+	+	+
Helicteres isora	Aatedi	Leaves	+	+	+
Heteropogon contorius	Kagadiyo	Whole plant	+	+	+
Heteropogon triticeous	Sokhal	Whole plant		+	+
Heylandia latebrosa	Makhni	Whole plant	+	+	+
Holarrhena antidysenterica	Kalokadu	Leaves		+	+
Holoptelea integrifolia	Saral	Leaves		+	
Indigofera cordifolia	Vekario	Whole plant			+
Ischaemum pilosum	Khev	Whole plant		+	+
Ischamum laxum	Surwali	Whole plant			+
Iseilema prostratum	Ghauli	Whole plant		+	
Ixora arborea	Nevri	Leaves		+	+
Lannea coromandelica	Moledo	Leaves	+	+	+
Lantana camara	Lantana	Leaves		+	+
Leptadenia reticulata	Kharkhodo	Leaves	+		
Leucas cephalotes	Kubdo	Leaves	+	+	+
Manilkara hexandra	Rayn	Leaves		+	
Miliusa tomentosa	Umadi	Leaves		+	+
Millettia racemosa	Malvelo	Leaves	+		+
Mitragyna parvifolia	Kalam	Leaves		+	+
Morinda tinctoria	Rangari	Leaves	+	+	+
Ocimum canum	Van Tulsi	Leaves		+	
Oplismenus burmanii	Pedu	Whole plant	+	+	+
Panicum spp	Gandharu	Whole plant	+	+	+
Paspalidium spp	Kodad	Whole plant	+	+	+
Peristrophe bicalyculata	Laho Aghedo	Leaves	+	+	+
Pterocarpus marsupium	Biyo	Leaves		+	
Pupalia lappacea	Zipti	Leaves	+	+	+
Rivea hypocrateriformis	Fang velo	Leaves	+		+
Schleichera olesa	Karpta	Fruits	+		
Schrebera swietenioides	Markho	Leaves			+
Securingea leucopyrus	Shinvi	Leaves	+	+	+
Sehima nervosum	Saro	Whole plant	+	+	+
Sesamum indicum	Kala tal	Whole plant	+		

Contd…

Plant Species	Local Name	Palatable Parts	Chital	Cattle	Buffalo
Sida codata	Doliu	Whole plant	+	+	+
Soyamida fabrifuga	Royn	Leaves		+	+
Sterculia urens	Kadayo	Leaves	+	+	+
Syzygium heyneanum	Jambu	Leaves & Fruits	+	+	+
Tamarindus indica	Aamli	Leaves	+	+	+
Terminalia bellirica	Baheda	Fruits	+		
Terminalia crenulata	Sajad	Leaves	+	+	+
Themeda cymbaria	Ratad	Whole plant	+	+	+
Triumfetta rotundifolia	Savarno	Leaves	+	+	+
Vernoia anthelmintica	Kali Jeeri	Whole plant	+		
Wrightia tinctoria	Dudhlo	Leaves	+	+	+
Xeromphis spinosa	Mindholi	Leaves	+		+
Xeromphis uliginosa	Gengdi ful	Flower	+		
Ziziphus mauritiana	Bordi	Leaves & Fruits	+	+	+
Ziziphus oenoplia	Kanthar	Leaves	+	+	+

Appendix – II: Two-Way ordered table for tree community structure carried out using Two Way Indicator Species Analysis (TWINSPAN) in the intensive study area of eastern Gir sanctuary.

```
                    11111111111111111111111111111111111111               11111                1111             1111
                  12333447011233444111223471222337271   1224666788888999000363333344555566667770017111234566789902571340
                  10267026906118136234595448348342603691183149624567049125080124579234535782340391239785802896847356960

  1  Amli      2---------------------------------1-2--1--2-----2-1--1---1---32-------1------21--------------------1  0000
  4  Bahedo    ------------------------------------------------------------------------1-------------------------  0000
  7  Biyo      ------------------------------------------------------------------------1----------1----2---------  0000
 10  Ekalkant  ------------------------------------------------------------------------------------------------  0000
 14  Haldarwo  ------------------------------------------------------------------------------------------4-------  0000
 16  Kadayo    ------------------------------------------------------------1-------------------------------------  0000
 17  Kalam     ----------------1-------------------------1-------------------------2-------------------------  0000
 18  karapti   ------------------------------------------------------1-----------------------------4----------  0000
 29  sarsado   ----------------------------------------2------3-1-----------------------------------1----------  0000
 32  Temerind  ------------------------------------------------------------2-----------------------------------  0000
 35  Umdi      ---------------1-----------------------------------------------1---------------------------------2  0000
 36  Wadlo     ------------------------------------------------------1-----------------------------3----------  0000
 39  Ghutbord  ------------------------------------------------------------------------------------------------  0000
 42  Kantharo  ------------------------------------------------------------1-------------------------------------  0000
 22  moledu    2--2322-------------------------------2---1---42---1----3-1--22---3--22-1-----22------1----------1--  0001
 27  saledi    -------32-----1-----1------------1-2------------3-------1--3-31-4-321-2-------------------------  0001
 38  Dudhiyo   --2-2-23-------------------1--2-22------11----------------3533231-43441143242244-----------------  0001
 19  Khakhro   ---------3--1--1-------------------------------------------------1---2--------2---------2-2---2  001
 20  Kher      ----2-----3------4524434333232222222--234-----4-23332122-3-1243-32----2222-33223443345453544424563 5-  001
 21  Markho    --------------------2----------2-4-----------------------------------------------------------------  001
 23  Piplo     -2------------------------------------------------------------------1-----------------------------  001
 28  Saral     ----------2-----------------------------------------------------------------------------------------  001
 30  Shemlo    ------1-------------------------2-------------------------------------------2--------------------  001
 31  Teak      52453433442555545425344454344443 32------------------3---4-------------------------------------  001
 33  Timru     --21-----34-1--22-----------1--2-2-------1-2-------------121---1-----------------------------3---133  001
 34  Ujjal     ------------1-----------------------------------------------------------------------------------  001
 37  dhraman   -2---2------1--12---1-1---------3--------1---------------------1------1-22--------------1----------  001
 40  Ingori    ---------------------3--------22------3-----------------------------------2---1----4---------1-----  001
 46  Nevri     ------------------------------2-----------------------------------------------------------------  001
  3  Babarkhe  -----213-------------2-----1---------------------------------2-------------1----------2---------  01
  6  bili      -2---2-------------------1---------------1-----------------------------------------------------  01
  9  Dhavda    ------------------------------1245444245343423434554442 3--432442323322-33--4445-24-3-3-23---1-1  01
 11  Garmalo   -------------1-----------------------------------------1--2-----------------------------------  01
 24  Rangari   -22-------2-------------------------------------------------------1--1----1--------------2-----1  01
 25  Royn      ---------------1-1----------------1---21--------2-------------1-----1-1---1----------1--1----------  01
 26  sajad     --------322--1------2-------1--2--142----42-24434222-3---------------2-2----2-----------2----1----2  01
 43  lodari    ------1-----1---------------------1-----------3----------1--------------2------------------------  01
 45  mindholi  ---1-----------------------------------------2--1-------------------------------1----------------  01
 48  Vadhvadi  ------------------------------------------------------------1------1-----------------2-------  01
  2  Asundro   ------------------------1-1-12-------------------2---------22-2-----222--1231--------------------  1
  5  Bawal     -2--3-----------------------------------2---------2---2----------1------1--11----------2-----2-----1  1
  8  Bordi     ---12------1------------2422223---22--3--222-------------21----1-----212311--12-3----12----2-12-4--  1
 12  Gengadi   ------------------------------------------2-------------------------------1---------1-------------  1
 13  Gorad     ------------------------------------------------------------------------------------------------  1
 15  Harmo     -2212-1-----------2-------1-------------------------1---------------------2---3-3--------2232----1  1
 41  Kalokadu  ------------------------------------------------------------------------------------------------  1
 44  Madham    --------1--------------------2-----23-1----------------------------1----1----------------------  1
 47  Shinvi    ------------------------------------------------------------------------------------------------  1

                  00000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000
                  00000000000000000000000000000000011111111111111111111111111111111111111111111111111111111111111111
                  00000000111111111111111111111111100000000000000000000000000000000000000000000000000000000000000000
                         000000000111111111111111111100000000000000000000000000000000000000000000000011111111111111111111
                                  0000000000000001100000000000000000000000001111111111111111111111000000000000000000111
                                  000000001111111  0   0 0      0   0 0 0
```

TWO-WAY ORDERED TABLE

```
                 111111  111111111                       111    11111       111       11111
                61555671700245666715 7   111244477 22224588455 3585566622458999146 33579903456
                67589230978252457746712457802480572349090380786011436956178137591537112569760

  1  Amli       --2-1---443-4-4-12-------------------------------------------------------------  0000
  4  Bahedo     -------------------------------------------------------------------------------  0000
  7  Biyo       1-2--1------------------------------------------------------------------------  0000
 10  Ekalkant   ----------------1-------------------------------------------------------------  0000
 14  Haldarwo   -------------------------------------------------------------------------------  0000
 16  Kadayo     -------------------------------------------------------------------------------  0000
 17  Kalam      -2------3---------------------------------------------------------------------  0000
 18  karapti    -----1-----3-----------------------------------------------------------------  0000
 29  sarsado    -----1----3-------------------------------------------------------------------  0000
 32  Temerind   -------------------------------------------------------------------------------  0000
 35  Umdi       ----11------------------------------------------------------------------------  0000
 36  Wadlo      -------------------------------------------------------------------------------  0000
 39  Ghutbord   -----------------2-------------------------------------------------------------  0000
 42  Kantharo   -------------------------------------------------------------------------------  0000
 22  moledu     3424113----2--231--2-------------------------2-------------------------------  0001
 27  saledi     -------4----2-42-2-----------------------------------------------------------  0001
 38  Dudhiyo    -----1--------------------------1----------------------2-----------1-------  0001
 19  Khakhro    -----------------2------------1-1-------------------------------------------  001
 20  Kher       1324424-----2---1-3442-----2342---------------2------13-2-21--2-----------1  001
 21  Markho     1---1-------------------------------------------------------------------------  001
 23  Piplo      -------------------------------------------------------------------------------  001
 28  Saral      --------3---------------------------------------------------------------------  001
 30  Shemlo     -------------------------------------------------------------------------------  001
 31  Teak       ------------------------------------------------------------43-3------------  001
 33  Timru      32---23-----2--2-2-----------------------------------------1-------1-------  001
 34  Ujjal      -------------------------------------------------------------------------------  001
 37  dhraman    ----1-------------------------------------------------------2----------1-  001
 40  Ingori     ---------4-5----1-------2--------------------------3--------------------1-  001
 46  Nevri      -------------------------------------------------------------------------------  001
  3  Babarkhe   --2----------3-2---------------------------------------------------------331  01
  6  bili       ------------------------------------------2-----------------------------  01
  9  Dhavda     1-----------------3-4443444242242----2--------------------------2---24------  01
 11  Garmalo    ---------------------------------1-------------------------------------------  01
 24  Rangari    ----12--------------------------1----------------------2-------2----1-------  01
 25  Royn       ---------------3---3-------------------------------------------4--4-----  01
 26  sajad      ---------2--241244--------1-----------------4-------3----2-3---------------  01
 43  lodari     ------------------------------------------------3-------------------------2  01
 45  mindholi   ------------------------------------------------------------------2-------  01
 48  Vadhvadi   ----1-------------------------------------------------------------1----------1  01
  2  Asundro    2---------------1-----24-----------------------------1--2------2----2-4---22  1
  5  Bawal      -----------------324-232-1---3-14543414-4552---------3424243-32-453-2442-511  1
  8  Bordi      -22-21---1------1-33-433343534244545545555-44546566546444444434441-3422-4--12  1
 12  Gengadi    -------------------------1--------------------2--------------------------1-  1
 13  Gorad      ------------------------------------------------------------------4---------  1
 15  Harmo      -------4--4--4--12-------21---1------------------------3-2221-4-2-4-12-46-11  1
 41  Kalokadu   -----2--------1-----------------------------------4------------------------  1
 44  Madham     1-------------2----------2232------2-3-44---2-----------------------------  1
 47  Shinvi     ------------------------------------------------------2--------------------  1

                00000000000000000011111111111111111111111111111111111111111111111111111111111
                11111111111111111100000000000000000000000000000000000000000000000011111111111
                00000001111111111100000000000000011111111111111111111111111111111111
                1111111           000111111111111000000000000000000000011111111111
                1111111                          00000000000111111111

                      ********** TWINSPAN completed **********
```

Appendix- III: List of plants encountered during vegetation sampling in eastern Gir sanctuary during winter 2006.

Scientific Name	Local Name	Habit
Apluda mutica	Foflu	H
Aristida adscensionis	Bhuklo	H
Barleria priontis	Aselio	H
Blepharis maderaspatensis	Kutelo	H
Borreria stricta	Dhrath	H
Cassia tora	Kuwadiyo	H
Chionachne koenigii	Garolu	H
Cyperus nutans	Saiyo	H
Dalechampla Scandens	Khajawani	H
Desmostachya bipinnata	Daraf	H
Dichanthium annulatum	Jinjwo	H
Echinochloa colonum	Sambo	H
Eragrostis poaeoides	Chakumaku	H
Eremopogon foveolatus	Shaniyar	H
Heteropogon contorius	Kagadiyo	H
Heteropogon triticeous	Sokhal	H
Ischaemum pilosum	Khev	H
Iseilema prostratum	Ghauli	H
Leucas cephalotes	Kubdo	H
Mimosa pudica	Rismani	H
Panicum sp.	Gandharu	H
Paspalidium sp	Kodad	H
Peristrophe bicalyculata	Laho Aghedo	H
Pupalia lappacea	Zipti	H
Sehima nervosum	Saro	H
Sesamum indicum	Tal	H

Contd..

Scientific Name	Local Name	Habit
Sida codata	Doliyu	H
Themeda cymbaria	Ratad	H
Tribulus terrestris	Gokharu	H
Vernoia anthelmintica	Kalijeeri	H
uniid	Chandaliyo	H
uniid	Dhimdo	H
uniid	Jambudiyu	H
uniid	Padajudee	H
uniid	Pandadiyo	H
uniid	Vekariyo	H
Aegel marmelos	Bili	S
Balanites aegyptica	Ingori	S
Capparis sepiaria	Kantharo	S
Carrisa carandas	Karamdi	S
Cissus repanda	Gandowelo	S
Dichrostachys cinerea	Madham	S
Ethritia laevis	Vadhvadiyo	S
Flacourtia indica	Lodari	S
Grewia hirsuta	Khad-dhramnu	S
Grewia tiliaefolia	Dhraman	S
Helicteres isora	Antedi	S
Holarrhena antidysenterica	Kalokadu	S
Ixora arborea	Nevri	S
Ocimum canum	Takmaria	S
Securingea leucopyrus	Shinvi	S
Triumfetta rotundifolia	Savarno	S
Xanthium strumarium	Gadardi	S

Contd…

Scientific Name	Local Name	Habit
Xeromphis spinosa	Mindholi	S
Xeromphis uliginosa	Gengadi	S
Ziziphus glaberrima	Ghutbordi	S
Ziziphus oenoplia	Kanthar	S
Acacia catechu	Kher	T
Acacia ferrungia	Babarkheri	T
Acacia leucophloea	Harmo	T
Acacia nilotica	Bawal	T
Acacia senegal	Gorad	T
Adina cordifolia	Haldarwo	T
Albizia odoratissima	Sarsado	T
Anogeissus latifolia	Dhavda	T
Azadirachta indica	Limdo	T
Bauhinia racemosa	Asundro	T
Bombax ceiba	Shemlo	T
Boswelia serrata	Saledi	T
Bridelia retusa	Ekalkanto	T
Butea monosperma	Khakhro	T
Butea monosperma	Khakharo	T
Cassia fistula	Garmalo	T
Diospyros melanoxylon	Timru	T
Emblica officinalis	Aamli	T
Ficus benghalensis	Wadlo	T
Ficus glomerata	Umro	T
Ficus religiosa	Piplo	T
Garuga pinnata	Karapti	T
Gmelina arborea	Savin	T

Contd…

Scientific Name	Local Name	Habit
Holoptelea integrifolia	Saral	T
Lannea coromondelica	Moledu	T
Miliusa tomentosa	Umdi	T
Mitragyna parvifolia	Kalam	T
Morinda tinctoria	Rangari	T
Pterocarpus marsupium	Biyo	T
Sapindus emarginatus	Arithi	T
Schleichera oleosa	Ujjal	T
Schrebera swietenioides	Markho	T
Soyamida fabrifuga	Royn	T
Sterculia urens	Kadayo	T
Tamarindus indica	Ambli	T
Tectona grandis	Sag	T
Terminalia bellirica	Bahedo	T
Terminalia crenulata	Sajad	T
Wrightia tinctoria	Dudhiyo	T
Ziziphus mauritiana	Bordi	T

Habit-
H- Herbaceous; S- Shrub; T- Tree